

THE RELATIONSHIP OF STRUCTURE  
OF GEORGIA KAOLIN TO ITS VISCOSITY

125

A THESIS

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by

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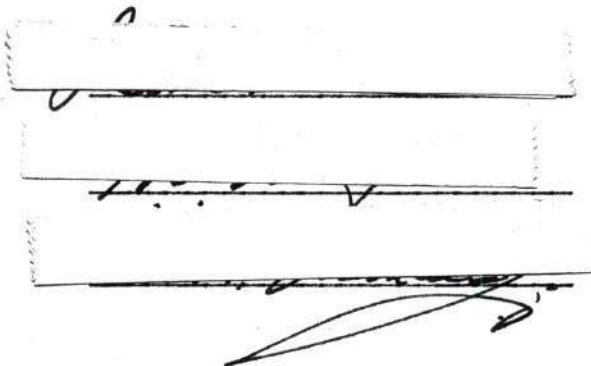
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THE RELATIONSHIP OF STRUCTURE  
OF GEORGIA KAOLIN TO ITS VISCOSITY

Approved:

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Date Approved by Chairman: \_\_\_\_\_

## ACKNOWLEDGEMENTS

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## SUMMARY

This investigation was primarily concerned with the causes of the variance in the viscosities of several Georgia kaolins.

The direct causes of the variance in viscosity of kaolin suspensions probably cannot be attributed to any one specific factor. It is well known that particle shape, size, concentration of suspension, the suspending medium, and added electrolytes affect the viscosity of a kaolin suspension. However, kaolins which were laid down at the same geological time may vary considerably in viscosity even though the factors mentioned above are rather similar.

Organic matter, either in the form of humic acid or microorganisms, was found to affect the viscosities of the investigated kaolins. Hydrogen peroxide was used to oxidize the organic matter, and the viscosity was determined for the raw and hydrogen peroxide treated kaolins in order to ascertain the effect that organic matter had on the viscosity of kaolin.

Extraneous attached ions, as was found by other investigators, affected the viscosities of the kaolins.

X-ray analysis indicated that hydrogen peroxide and electrodialysis treatments tended to alter the random dis-

placements of the lattice layers of the kaolins; however, the random displacement of the crystal lattice layers did not seem to affect the viscosities of the kaolins.

Electron micrographs revealed that the mineral kaolinite was predominant in the kaolins; however, halloysite was found to be present in the kaolins from Washington County, Georgia. The mineral dickite also appeared to be present in these kaolins.

## CHAPTER I

### INTRODUCTION

One of the problems that confronts the producers who use kaolin in the manufacture of ceramic products is the effect of kaolin on the workability of the particular body that is being used in the manufacturing process. Involved in the workability of a clay are such factors as plasticity, viscosity, and green strength. While these properties vary greatly with clays of different chemical composition, they also vary among kaolins composed of the mineral kaolinite.

This paper is primarily concerned with the causes of the variance in the viscosities of several Georgia kaolins.

Before discussing the probable causes of the variance in the viscosities of kaolinite type kaolins, a review of what is meant by viscosity and related terminology is appropriate. Viscosity is defined simply as that property of a material which causes it to resist flow. Or, viscosity is more appropriately defined as being proportional to the shearing stress divided by the rate of shear. The unit of measurement of viscosity is the poise, and a material has a viscosity of one poise when a shearing force of  $1 \text{ dyne/cm}^2$  produces a velocity gradient of  $1 \text{ cm/sec/cm}$ .



A clay suspension may not flow whenever the concentration of the suspension is somewhat high and the force that is used to make the suspension flow is small. The reason for this characteristic is that a clay suspension is not a true, or Newtonian liquid. It is generally accepted that a true, or Newtonian liquid flows when subjected to any force, no matter how small, but a plastic flows only when this force exceeds a certain minimum value. This minimum value is called "yield point." Clay suspensions are termed plastics for they are not homogeneous material and they possess a structure, an inner mechanism composed of dispersed particles, which causes such suspensions to have a yield point. Before the viscosity of a clay suspension can be obtained, the yield point of the suspension must first be overcome. This fact is one of the reasons why the viscosity of plastics or pseudo plastics cannot be obtained by single point viscosity methods.

Thixotropy is generally accepted as the property which involves transition from a jelly to a liquid upon agitation, and return to a jelly upon subsequent rest. Clays usually exhibit thixotropic behavior.

Dilatancy is a property of a material which causes the resistance to flow to increase at a greater rate than the increase in the rate of flow. Wet sea sand and quicksand are examples of materials having dilatant properties.

If a quick pressure is applied to the surface, the sand is rigid and solid; but if a slow sustained pressure is applied to the surface, the sand will flow and envelope the object causing the slow, sustained pressure.

The direct causes of the variance in viscosity of kaolin suspensions probably cannot be attributed to any one specific factor. It is well known that particle shape, size, concentration of the suspension, the suspending medium, and added electrolytes affect the viscosity of a kaolin suspension. However, kaolins which were laid down at the same geological time may vary considerably in viscosity even though the factors mentioned above are rather similar. It is thought that organic matter, in the form of humic acid or microorganisms that may be found in the kaolin deposits, and the structure of the kaolin particles may also be important factors in the causes of the variance in viscosity of kaolinite kaolins. It is also thought that organic matter or salts, if present in kaolins, may tend to exhibit electrolytic properties or may form buffer solutions, and thus disperse the kaolin particles into a deflocculated state. It is possible that a kaolinite kaolin may not be crystallized in an orderly arrangement, but may be crystallized in randomly displaced layers. Thus, a kaolinite particle having randomly displaced layers may have more unsatisfied charges than a well crystallized kaolinite particle of



the same size. If this is true, then the kaolinite particle having randomly displaced layers will tend to have greater adsorptive properties than the well crystallized kaolinite particle of the same size.

As stated before, it is believed that the direct causes for the variance in viscosity of kaolins cannot be attributed to any one specific factor; however, it is hoped that this investigation will be of some value in the determination of some of the causes of the variance in viscosities of several Georgia kaolins.



## CHAPTER II

### REVIEW OF THE LITERATURE

Kaolins are usually composed of aggregates of scales or plates of the mineral kaolinite. The mineral is plastic and highly refractory, having a fusion point near cone 36. The mineral kaolinite is commonly regarded as the base of clays (4). This fact has been established with X-ray diffraction and electron micrograph techniques.

Halloysite is related to kaolinite in the sense that both minerals are hydrated silicates of alumina. It differs from kaolinite in chemical character by containing slightly more water. A material once confusingly called halloysite is the mineral endellite which contains twice as much water as the normal kaolinite molecule. It is now accepted that halloysite is a partial dehydration product of endellite. It has been found in primary clays at several places in Georgia, but has not been recognized in the sedimentary kaolins (5). It has been found in Dade and Meriwether counties (5a), Northwest Georgia and Cartersville area (6). Halloysite differs from kaolinite in the crystalline form. It has a rod-like form whereas kaolinite has a hexagonal plate-like form (7).

Marshall (7a) states that colloidal properties are in general, exhibited by materials having one or more dimensions less than 0.1 micron ( $10^{-5}$  cm.). Particles having dimensions larger than 1 micron are generally regarded as being outside the colloidal range. Hauser (8) defines the colloidal range as being within the boundaries of 500 and 1 millimicron ( $10^{-7}$  cm.).

Marshall (7a) says, "Small particle size frequently reflects certain aspects of mineral structure. A slow rate of crystallization, a very facile cleavage, or ready abrasion, all of these are consequences of the atomic arrangement, and all favor the formation, or the subsequent production of small particles. It is believed also that strains introduced into silicate lattices by the presence of somewhat ill fitting atoms are an important cause of limited growth, and hence favor crystals of colloidal size."

Particle size may be a determining factor of some of the physical properties of a kaolin. Mitchell (9) found that the hardness of a kaolin as determined by the producers was found to be directly related to particle size, that is, the finer the grain size, the harder the clay.

The determination of particle size is rather difficult. There are several methods of determining particle size (10). Fischer (10a) has found that a number of investigators report satisfactory results with the use of the

hydrometer method of determining particle size, and that it provides a standardized test (3).

Johnson and Lawrence (11) studied monodisperse fractions of kaolinite and the exchange capacity was determined from the viscosity relations on additions of NaOH to the electrodialyzed fractions. They found that a linear relationship existed between the surface area and the base exchange capacity for all of the sizes studied.

Coughanour and Norton (12) studied the flow properties of suspensions containing monodisperse particles of kaolinite and halloysite. These suspensions were measured for their flow characteristics at various concentrations to determine the influence of particle shape. It was found that the particle shape had a considerable effect in dispersed suspensions. The particle attaining an isometric shape yielded the lower viscosity. Hauser's (13) findings agree with Coughanour and Norton.

Hauser (13) explains that the electric double layer surrounding the particles exerts a resistance to the flow of the dispersing medium, thereby increasing the viscosity.

Norton, Johnson and Lawrence (14) found empirical equations connecting viscosity, thixotropic coefficient, and yield point, each with concentration. The effect of particle size varied according to the cationic state of the kaolinite. The hydrogen clay showed a marked increase in viscosity with diminishing particle size.

Marshall (15) claims that relatively few measurements of viscosity have been made on well-defined clay minerals of known particle size. The electron microscope provides a direct method for the observations of the sizes and shapes of clay particles (15a). Green (16) explains that the limit of resolution of the electron microscope is usually placed at 40 angstroms, and that it would be more practical to place the resolving power at 100 angstroms, or 0.01 micron.

Fischer (17) claims that the method of X-ray diffraction has special uses such as an indication of grain size in a composite mass, and analysis below the practical limit of the electron microscope.



## CHAPTER III

## PROCEDURE

Seven samples of Georgia kaolin from the counties Twiggs, Washington, and Wilkinson were investigated. The kaolin samples were numbered, and a list of these numbered Georgia kaolins and the counties from which they were obtained is as follows:

<u>Sample Number</u>	<u>County</u>
1	Wilkinson
2	Wilkinson
3	Twiggs
4	Washington
5	Twiggs
6	Washington
7	Washington

The kaolin samples listed above were of a raw state when this investigation was begun.

Removal of Organic Matter.--The kaolin samples were powdered with the use of a porcelain mortar and pestle and were then blunged in distilled water. The slip was screened through a 100-mesh screen to remove any grit that may have been present. About 1 per cent of 30 per cent  $H_2O_2$  (based on the clay weight) was added to the slip, and the reaction was

allowed to proceed at room temperature with frequent agitation of the slip. As the reaction subsided, more  $H_2O_2$  was added to the slip and agitated as was done before. The addition of  $H_2O_2$  was continued until the evolution of gases (probably  $CO_2$ ) had ceased. The method used for the removal of the organic matter in this investigation, is in accordance with Norton's and Johnson's prescribed method (1).

Electrodialysis Process.--Three Mattson cells were made of a high alumina body and fired to vitrification. The cells were made in accordance with the cell design of Fig. 1. This smaller cell was made for the sole purpose of its utility. The capacity of this cell was 110 to 130 ml. The center compartment was made of a semi-hard rubber. The cells were held together by two clamps and the compartments were separated by parchment membranes. The anode was a platinum sheet 2 x 2 inches and the cathod was a copper sheet 2 x 2 inches. A current of 110 volts D.C. was used.

The  $H_2O_2$  treated kaolin slips were placed in the center compartments of the Mattson cells described above and the dialysis was considered complete when there was no change in the pH of the suspension (1).

Upon the completion of the electrodialysis, the kaolin samples were removed from the Mattson cells and placed into stoppered glass flasks. Solid suspensions of the kaolin samples were prepared as outlined in part 3, vis-

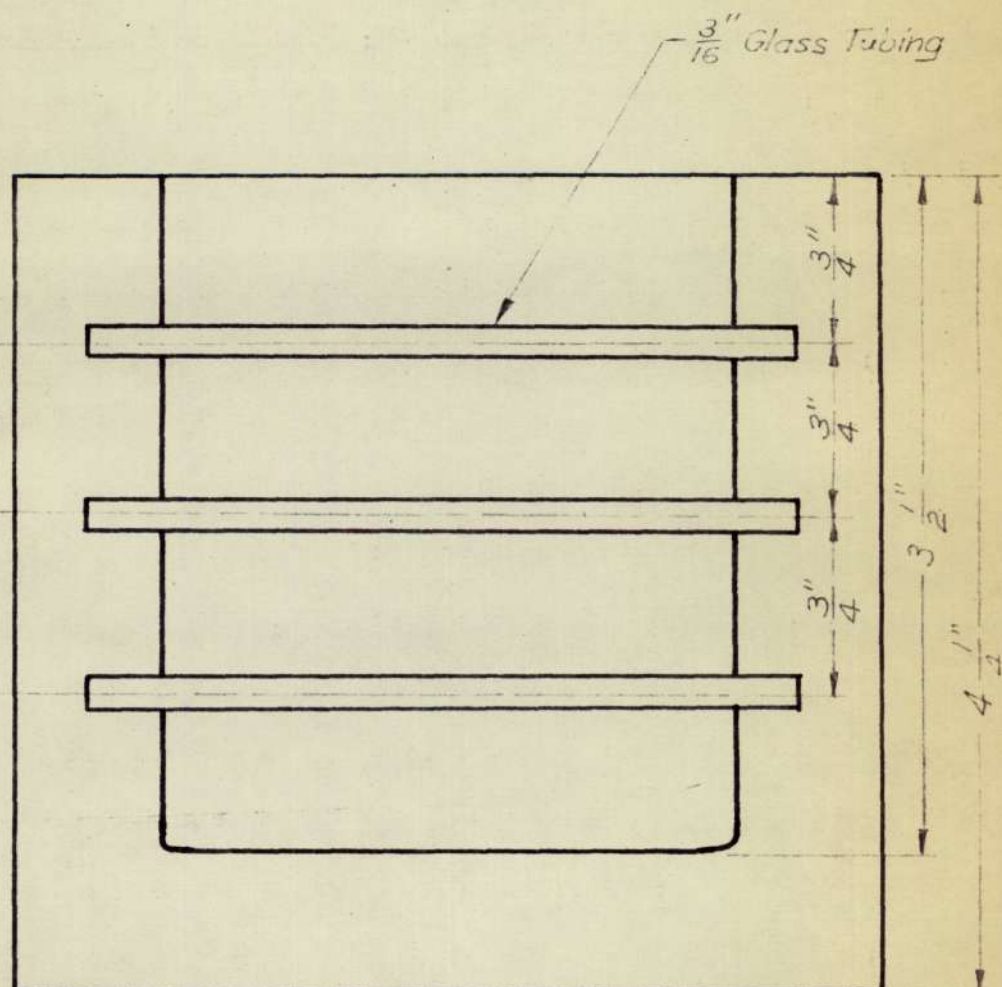
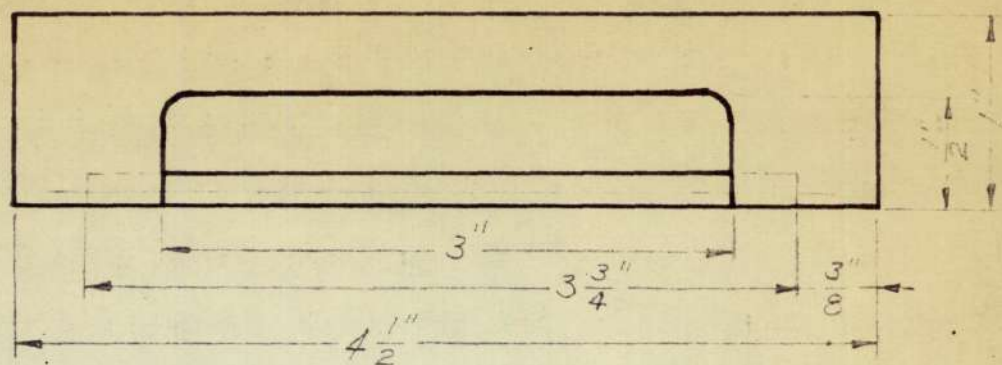


Fig. 1  
Electrodialysis Cell



cosity determination. Their viscosities and corresponding pH values were obtained.

Viscosity Determination.--The viscosities of the raw,  $H_2O_2$  treated, and dialyzed kaolin samples were determined with the use of a Brookfield viscometer. The principle upon which this viscometer operates is the measurement of the drag produced upon a spindle rotating at a definite constant speed while immersed in a material under test. This drag is indicated on a rotating dial by a pointer which is attached to the spindle shaft and represents the tension produced on a spiral spring, the core of which is fastened to the spindle shaft and the outside coil terminal to the dial which is directly connected to the motor shaft. This instrument is calibrated to Bureau of Standards values on the basis of immersion in an infinite body. It is accurate within 1 per cent of full scale of the dial.

Suspensions of the samples mentioned above were prepared so that the per cent solid concentration for the suspensions was 20, 18, 16, 14, and 12 per cent, and distilled water was used as the suspending medium. The viscosity was determined for each sample having the per cent solid concentration listed above. The temperatures of the suspensions were held constant at  $19.4^{\circ}C$ . Two readings were obtained for each point and the recorded reading is an average of these two readings.



pH Determination.--The pH was determined before and after the viscosity was obtained for every per cent solid concentration for each sample. A Coleman Compax pH Electrometer was used to obtain these pH values.

Particle Size Determination.--The particle size of each kaolin sample was determined using the prescribed method of the A.S.T.M. Designation: D422-39. The raw kaolin samples were mixed in a Hamilton Beach Blender for a period of 10 minutes. The electrolyte that was used was 0.4 per cent T.S.P.P./100 gm. of kaolin. The suspension was allowed to stand for a period of 18 hours before any readings were taken, the purpose being to allow the suspensions to reach a constant temperature of  $19.4^{\circ}\text{C}$ . This temperature was held constant throughout the entire particle size determination with the use of constant temperature bath. The hydrometer which was used was an A.S.T.M. type 'A' hydrometer. The recorded readings are an average of three readings for the first five readings. The reason being that the time period for each reading is very short. The time periods for the first five readings were  $\frac{1}{2}$ , 1, 2, 3, and 4 minutes. To illustrate more clearly, the suspension was shaken carefully for a period of 1 minute, then the suspension was allowed to stand for  $\frac{1}{2}$  minute. At this time a reading was taken, and at the end of 1 minute the second reading was taken, then at the end of 2 minutes the third reading was taken, etc.

Differential Thermal Analysis.--The electrolyzed kaolin samples were used for the thermal analysis. Dehydrated alumina was used for the reference sample. Equal weights of the kaolin sample and the dehydrated alumina were placed in the corresponding cavities of the nickel crucible. New chromel alumel thermocouples were prepared for each kaolin sample that was analyzed. The thermocouples were placed in the center of each cavity of the nickel crucible and the samples were firmly tamped around the thermocouples to insure good thermal conductivity. The furnace, a resistance type, was heated at a rate of  $8^{\circ}\text{C}$  per minute until a temperature of  $1000^{\circ}\text{C}$  was reached. It was assumed that all reactions had taken place within the range of  $20^{\circ}\text{C}$  to  $1000^{\circ}\text{C}$ . A plot was made for each kaolin sample analyzed. The plot indicates the thermal reactions, endothermic and exothermic, and the temperatures at which these reactions took place.

X-ray Diffraction.--X-ray analysis was made on the raw, organic free, and dialyzed kaolin samples. The powdered specimen technique was used for obtaining the X-ray diffraction. The North American Philips wide range diffractometer was used. A  $1^{\circ}$  scatter slit, and a 3 mil receiving slit was used. The scanning speed was  $\frac{1}{4}^{\circ}$  per minute. The instrument was a recording type, and the values of the random displacement of the kaolin samples tested were obtained from the recorded plot.



Electron Micrographs.--A model E.M.U.-2, R.C.A. electron microscope was used to obtain micrographs of the kaolin samples. Micrographs were made of the raw kaolin samples. The kaolin samples were powdered with a mortar and pestle. A suspension of 0.5 per cent solids using distilled water as the suspending medium was prepared from the powdered kaolin samples. A suitable amount of dispersing agent was added and the suspension was mixed in a Waring blender for a period of two minutes. The mixed suspension was allowed to stand for 1 minute so that the largest particles would settle out. A portion of the suspension was removed and placed on a prepared screen. After the water was evaporated from the specimen on the prepared screen, the specimen was placed into the electron microscope for examination.

## CHAPTER IV

### DISCUSSION OF RESULTS

The purpose of this paper, as stated in the Introduction, was an attempt to determine the cause of the variances in viscosities of several Georgia kaolins.

In order to determine to what extent organic matter and extraneous attached ions affected the viscosity of a particular kaolin, the viscosity was determined for the raw, organic free, and the electrodialyzed kaolins. It was assumed that the electrodialyzed kaolin was kaolin in its purest form. Thus, the electrodialyzed kaolin could be used as a datum.

The tables and figures that are discussed in this chapter may be found in the appendix. The data listed in Tables 1 through 7 is the recorded measurements of the viscosities and pH of the kaolins investigated while varying the per cent solids in suspension and the velocity of the rotating spindle of the viscometer. The per cent solid suspension was varied so as to obtain the apparent viscosity of the suspension. Although this method is in reality a one point viscosity check, it is the method which the ceramist would use to alter the viscosity of a suspension; however, the rate of shear was varied so that the viscosity

with this variable could be observed and to determine if the suspension was thixotropic or dilatent.

The pH was obtained for the raw, organic free, and electrodialed kaolin samples so as to observe the effects that the organic matter and extraneous attached ions may have on the hydrogen ion concentration of the suspension.

Figs. 2 through 7 are the plots of the apparent viscosity verses the per cent solid concentration of the suspensions for raw, organic free, and electrodialed kaolin samples. The viscosity values of these figures are those values which were obtained for a spindle velocity of 60 r.p.m. By observing these figures, it can be seen that organic matter in the investigated kaolins does in general affect their viscosities. By comparing the viscosity figures of the raw kaolins with the organic free kaolins, it can be seen that the viscosity dropped after the kaolins were freed of organic matter. This was true for all of the kaolins investigated with the exception of kaolin sample No.2 which showed a slight increase in viscosity upon removal of organic matter. The attached extraneous ions lowered the viscosity of the kaolin samples Nos. 1, 2, 5, and 6. The viscosity of the kaolin samples Nos. 3, 4, and 7 was increased by the attached extraneous ions. This can be seen by comparing the viscosity figures of the dialyzed kaolins with the organic free kaolins. It was assumed that a dia-



lyzed kaolin would exhibit higher viscosities since the electrical double layer of a particle would become smaller upon dialysis and the replacement of the attached ions by hydrogen ions would make the particle electrically neutral and thus favor the coalescing of particles to form aggregates which would increase the drag on a rotating spindle of a torsion type viscometer. These kaolins seemed to be in a deflocculated state. It is usually assumed that a dialyzed kaolin has hydrogen ions attached to it; however, if a dialyzed kaolin were positively charged, it would attract the hydroxyl ions. Since the hydroxyl ions are larger than the hydrogen ions, the surface of the kaolinite particle would accommodate fewer hydroxyl ions. Thus, the kaolin particle may have unsatisfied charges which would cause the particles to be in a deflocculated state and exhibit low viscosity properties. Another possibility for deflocculation under an acid condition seems to lie in the situation where small aggregated clay particles have an internal negative charge which is not satisfied by the hydrogen ions adsorbed on the surface. The clay micelles are then larger and have residual repulsive charges which promote deflocculation. The electrodialysis process may have altered the particles in some way so that their viscosities became lower. No direct cause could be found for this decrease in viscosity upon electrodialysis of kaolin samples Nos. 3, 4, and 7.

The pH determinations indicate that organic matter increases the acidity of the kaolins slightly. This was true for all the kaolins investigated with the exception of kaolin samples Nos. 1 and 6. The amount of organic matter that may be present in kaolin is very difficult to determine, and no precise method could be found in order to determine the quantity of organic matter in kaolins. Table 9 is the chemical analysis of the kaolins investigated, and the per cent organic matter is a portion of the per cent ignition loss. Kaolin sample No. 2 has a slightly alkaline pH value, and this may be due to the MgO or CaO present in the kaolin. The pH values for the dialyzed kaolin samples are within expected values; however, the pH value for kaolin sample No. 7 is very low.

All of the kaolin samples investigated were found to be thixotropic over the range of shearing rate studied. Their viscosities decreased as the rate of shear or the spindle speed was increased. This can be seen by observing the recorded viscosities with the corresponding increase in velocity of the spindle on Tables 1 through 7.

Table 8 is the particle size distributions of the kaolin samples that were investigated. Fig. 9 is a characteristic grain size accumulative curve of the investigated samples. Kaolin samples Nos. 3 and 4 did not differ to any great extent in their particle size distributions. By com-



paring the viscosities of kaolin samples Nos. 3 and 4, it can be seen that their viscosities differ yet they have similar particle size distributions. Thus, it is evident that particle size alone is not entirely responsible for the variance in viscosity of Georgia kaolins.

The chemical analysis, Table 9, indicates a larger percentage of MgO than CaO. This is not in agreement with other chemical analyses of Georgia kaolins. The per cent MgO is usually very small or absent in Georgia kaolins.

Figs. 10 through 13 are the differential thermal analysis curves of the kaolins investigated. The dehydration and endothermic peaks have slight temperature variation among the kaolins investigated. This variance is probably due to the degree of crystalline perfection of the mineral kaolinite (17). The curves are all characteristic kaolin thermal curves; however, their peaks, endothermic and exothermic vary in the magnitude of their areas. The differences in the endothermic peaks, as stated previously, are probably due to the arrangement of the crystal lattice layers. The differences of the exothermic peaks are probably due to the silica attachment to the amorphous alumina. It is generally accepted that the exothermic reaction that occurs between  $900^{\circ}$  to  $1050^{\circ}\text{C}$  is due to the crystallization of amorphous or semi-amorphous alumina to gamma alumina.



Table 10 is a list of the intensity ratios or random displacements of the lattice layers and the approximate C dimensions of the kaolins that were investigated. These values were obtained from the recorded plots of the X-ray analyses. Fig. 14 is the recorded plots of two of the samples. The values of the random displacements are whole numbers, and the largest number represents the least random displacement of the lattice layers. Perfect arrangement of the lattice layers of a crystal would give high values for its intensity ratios. It appears from the X-ray analysis that the removal of organic matter with the use of  $H_2O_2$  and the electrodialysis tended to alter the random displacement of the lattice layers of the kaolins that were investigated. By comparing the viscosities of the kaolins with their intensity ratios no correlation could be found that would indicate that random displacement of the lattice layers affected their viscosities. If no correlation exists between these two factors, the random displacements of the lattice layers have no effect on the viscosities of the kaolins that were investigated. If a correlation could be found between the two factors mentioned above it would probably be of value in determining the causes of the variances in the viscosities of Georgia kaolins.

Figs. 15 through 23 are electron micrographs of the kaolins that were investigated. By observing these figures,

it can be seen that kaolinite is prevalent in all these kaolins. Fig. 18 is an excellent micrograph of the card-deck stack of the mineral kaolinite. This stacking of the kaolinite is a usual characteristic of sedimentary kaolinite. Note the rod-like shape in the lower left hand corner of Fig. 19, kaolin sample No. 4. The crystal shown has the split characteristic of halloysite. This evidence indicates that halloysite is present in this kaolin. Dickite also appears to be present in this kaolin, Figs. 18 and 19. Halloysite appears to be present in kaolin sample No. 7, Fig. 22. Since the presence of halloysite was found in two of the kaolins that were investigated, it is thought that these kaolins are true sediments which were transported from the weathered mother rock and deposited in their present location. It is hoped that this finding will be of some value in any controversies that may exist as to the origin of the sedimentary kaolins of Georgia.

## CHAPTER V

### CONCLUSIONS

The following factors were found to affect the viscosities and to cause variances in the viscosities of the Georgia kaolins that were investigated:

1. Particle size and its distribution.
2. Particle shape.
3. Extraneous ions that may be attached to the particles.
4. Organic matter which may be attached or near the particles.

The following are findings which were observed in this investigation:

1. Halloysite was identified as being present in the sedimentary Georgia Kaolin of Washington County.
2. Kaolinite was the predominant mineral in the sedimentary kaolins of Georgia; however, other kaolin minerals were found to be present.
3. The random displacement of the crystal lattice layers did not seem to affect the viscosities of the kaolins.
4. The removal of the organic matter with the use of  $H_2O_2$  seemed to affect the displacement of the lattice layers of the kaolin crystals.

5. The removal of extraneous ions by electrodialysis seemed to affect the displacement of the lattice layers of the kaolin crystals.

## A P P E N D I X

Table 1

Viscosity Obtained Using Brookfield Viscometer and Using Spindle #2

Kaolin Sample No. 1

% Solids	pH Raw Clay	pH H <sub>2</sub> O <sub>2</sub> Treated Clay	pH Dialyzed Clay	r.p.m.	Viscosity Raw Clay (cps)	Viscosity H <sub>2</sub> O <sub>2</sub> Treated Clay (cps)	Viscosity Dialyzed Clay (cps)
20	4.80	4.31	3.95	12 30 60	286 131 77	226 106 64	526 229 124
18	4.90	4.62	4.00	12 30 60	214 101 61	114 65 44	389 171 94
16	4.90	4.60	4.10	12 30 60	146 73 44	64 35 24	191 96 56
14	4.90	4.58	4.15	12 30 60	66 41 26	1 7 8	114 56 34
12	5.00	4.58	4.15	12 30 60	51 26 17	1 1 1	64 39 27



Table 2

## Viscosity Obtained Using Brookfield Viscometer and Using Spindle # 2

Kaolin Sample No. 2

% Solids	pH Raw Clay	pH H <sub>2</sub> O <sub>2</sub> Treated Clay	pH Dialyzed Clay	r.p.m.	Viscosity Raw Clay (cps)	Viscosity H <sub>2</sub> O <sub>2</sub> Treated Clay (cps)	Viscosity Dialyzed Clay (cps)
20	7.70	7.50	3.85	12 30 60	701 328 189	659 326 189	839 389 220
18	7.60	7.85	3.90	12 30 60	501 233 144	554 256 145	726 346 139
16	7.60	7.80	3.95	12 30 60	326 153 98	374 181 109	501 229 129
14	7.65	7.75	4.00	12 30 60	191 96 59	214 110 74	276 125 71
12	7.65	7.65	4.00	12 30 60	126 67 48	126 70 47	146 86 51

Table 3

Viscosity Obtained Using Brookfield Viscometer and Using Spindle #2

Kaolin Sample No. 3

% Solids	pH Raw Clay	pH H <sub>2</sub> O <sub>2</sub> Treated Clay	pH Dialyzed Clay	r.p.m.	Viscosity Raw Clay (cps)	Viscosity H <sub>2</sub> O <sub>2</sub> Treated Clay (cps)	Viscosity Dialyzed Clay (cps)
20	4.75	5.00	4.30	12 30 60	576 263 148	426 211 125	364 176 101
18	4.95	5.00	4.30	12 30 60	414 196 114	321 156 91	276 131 81
16	5.00	5.10	4.40	12 30 60	289 137 77	231 109 60	189 101 59
14	5.09	5.10	4.50	12 30 60	181 83 48	139 61 39	114 59 36
12	5.12	5.18	4.55	12 30 60	111 55 37	89 51 34	89 43 29



Table 4

Viscosity Obtained Using Brookfield Viscometer and Using Spindle #2

Kaolin Sample No. 4

% Solids	pH Raw Clay	pH H <sub>2</sub> O <sub>2</sub> Treated Clay	pH Dialyzed Clay	r.p.m.	Viscosity Raw Clay (cps)	Viscosity H <sub>2</sub> O <sub>2</sub> Treated Clay (cps)	Viscosity Dialyzed Clay (cps)
20	4.42	4.98	4.20	12 30 60	794 367 200	626 296 164	426 196 124
18	4.80	5.00	4.40	12 30 60	604 266 151	491 221 128	321 156 90
16	4.90	5.10	4.45	12 30 60	411 183 109	364 157 92	226 123 72
14	4.92	4.90	4.45	12 30 60	239 116 66	201 91 54	146 71 44
12	4.95	4.90	4.50	12 30 60	176 77 44	144 66 39	101 51 32

Table 5

Viscosity Obtained Using Brookfield Viscometer and Using Spindle #2

Kaolin Sample No. 5

% Solids	pH Raw Clay	pH H <sub>2</sub> O <sub>2</sub> Treated Clay	pH Dialyzed Clay	r.p.m.	Viscosity Raw Clay (cps)	Viscosity H <sub>2</sub> O <sub>2</sub> Treated Clay (cps)	Viscosity Dialyzed Clay (cps)
20	3.90	4.90	3.90	12 30 60	711 323 174	516 225 129	1026 457 239
18	4.25	4.90	3.95	12 30 60	531 231 126	361 167 94	714 306 161
16	4.39	5.00	4.10	12 30 60	366 163 94	251 120 69	491 217 118
14	4.49	5.10	4.15	12 30 60	206 95 54	154 72 43	289 121 71
12	4.55	5.10	4.20	12 30 60	126 61 37	126 56 34	189 91 54



Table 6

## Viscosity Obtained Using Brookfield Viscometer and Using Spindle # 2

Kaolin Sample No. 6

% Solids	pH Raw Clay	pH H <sub>2</sub> O <sub>2</sub> Treated Clay	pH Dialyzed Clay	r.p.m.	Viscosity Raw Clay (cps)	Viscosity H <sub>2</sub> O <sub>2</sub> Treated Clay (cps)	Viscosity Dialyzed Clay (cps)
20	5.10	4.90	4.00	12 30 60	751 356 202	771 354 194	1251 579 339
18	5.12	5.00	4.05	12 30 60	566 261 149	608 268 149	936 435 248
16	5.15	5.00	4.10	12 30 60	414 191 113	414 188 108	671 321 180
14	5.20	5.00	4.15	12 30 60	251 121 71	261 116 66	401 191 109
12	5.20	5.00	4.25	12 30 60	176 86 49	164 77 43	264 126 74



Table 7

Viscosity Obtained Using Brookfield Viscometer and Using Spindle # 2

Kaolin Sample No. 7

% Solids	pH Raw Clay	pH H <sub>2</sub> O <sub>2</sub> Treated Clay	pH Dialyzed Clay	r.p.m.	Viscosity Raw Clay (cps)	Viscosity H <sub>2</sub> O <sub>2</sub> Treated Clay (cps)	Viscosity Dialyzed Clay (cps)
20	4.40	4.70	2.75	12 30 60	139 68 42	149 70 42	1 9 11
18	4.60	4.80	2.80	12 30 60	126 61 37	101 51 31	1 6 9
16	4.60	4.80	2.85	12 30 60	101 53 31	51 31 21	1 5 6
14	4.70	4.90	2.90	12 30 60	56 31 24	26 16 14	1 5 5
12	4.70	5.00	2.95	12 30 60	39 21 16	14 11 9	1 5 6



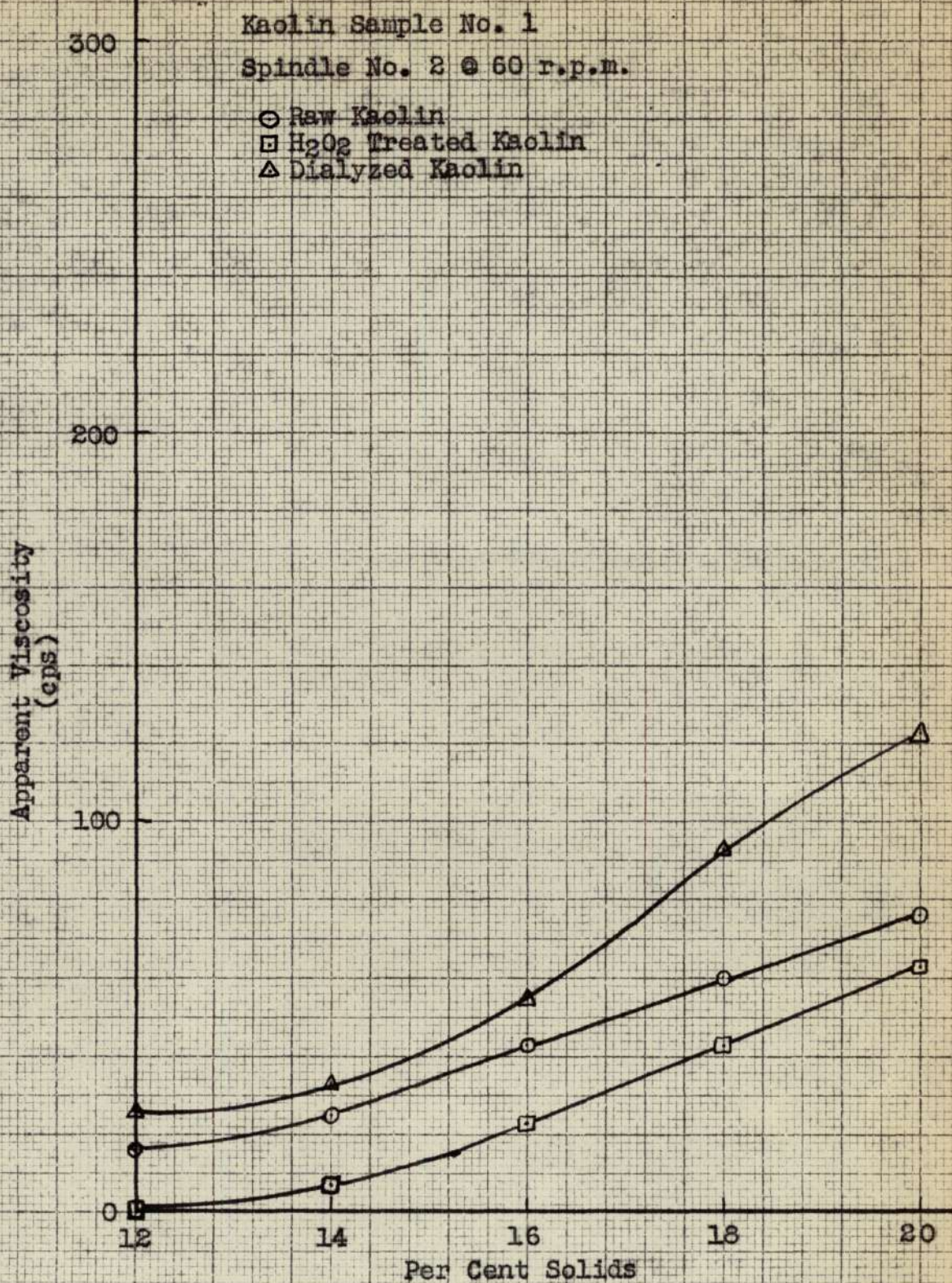


Fig. 2  
Apparent Viscosity Versus Per Cent Solids



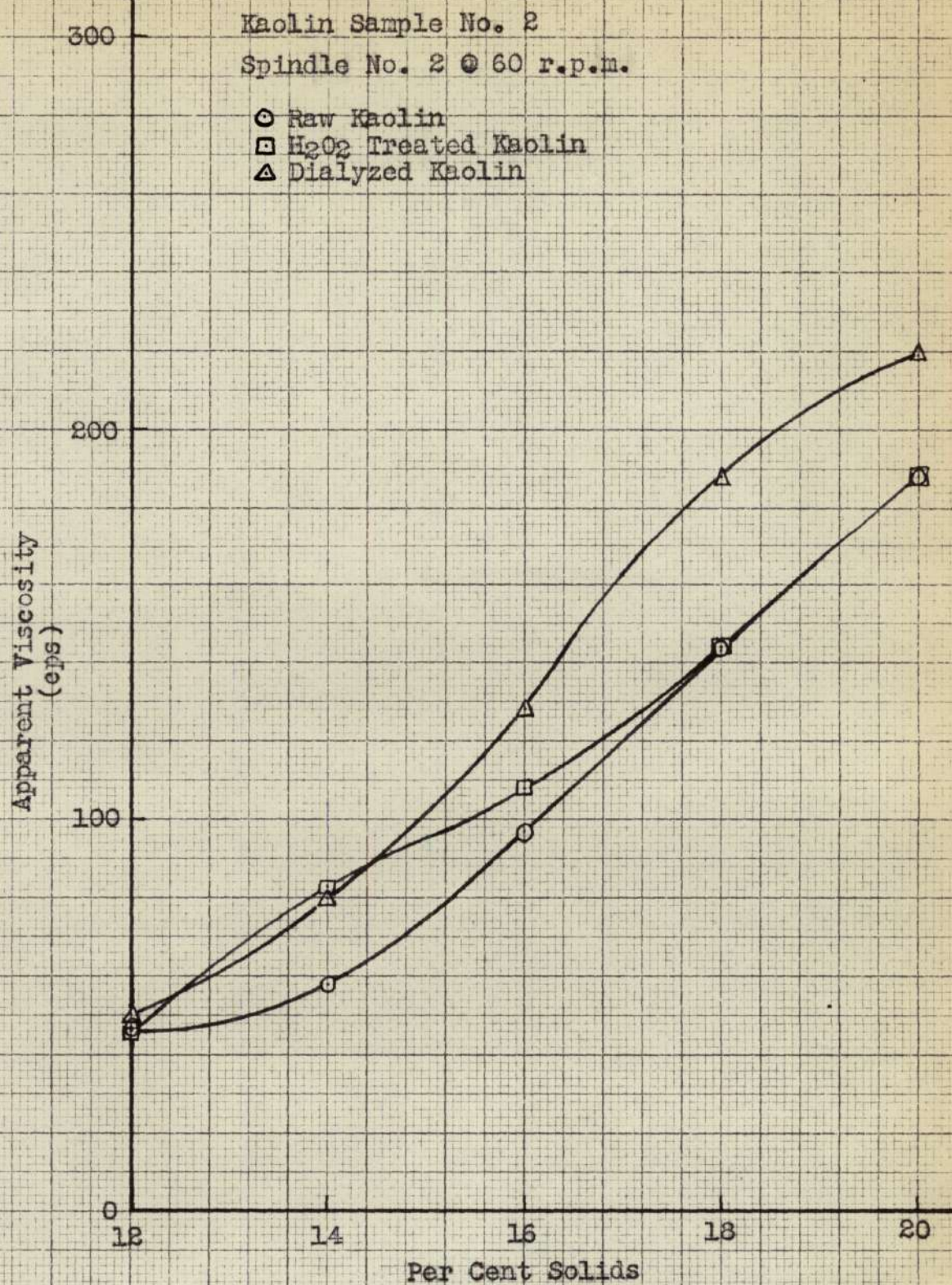


Fig. 3  
Apparent Viscosity Versus Per Cent Solids



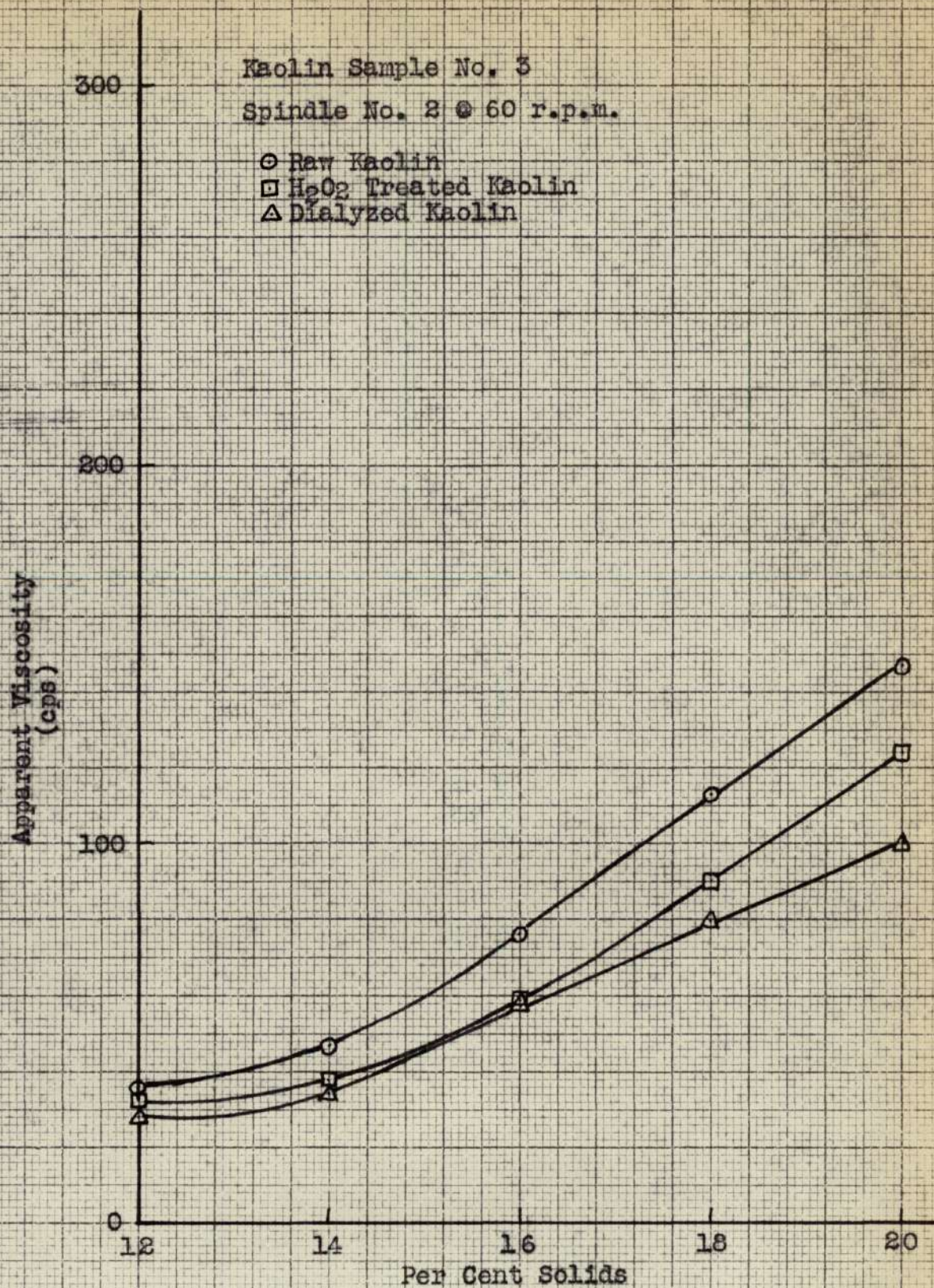


Fig. 4  
Apparent Viscosity Versus Per Cent Solids



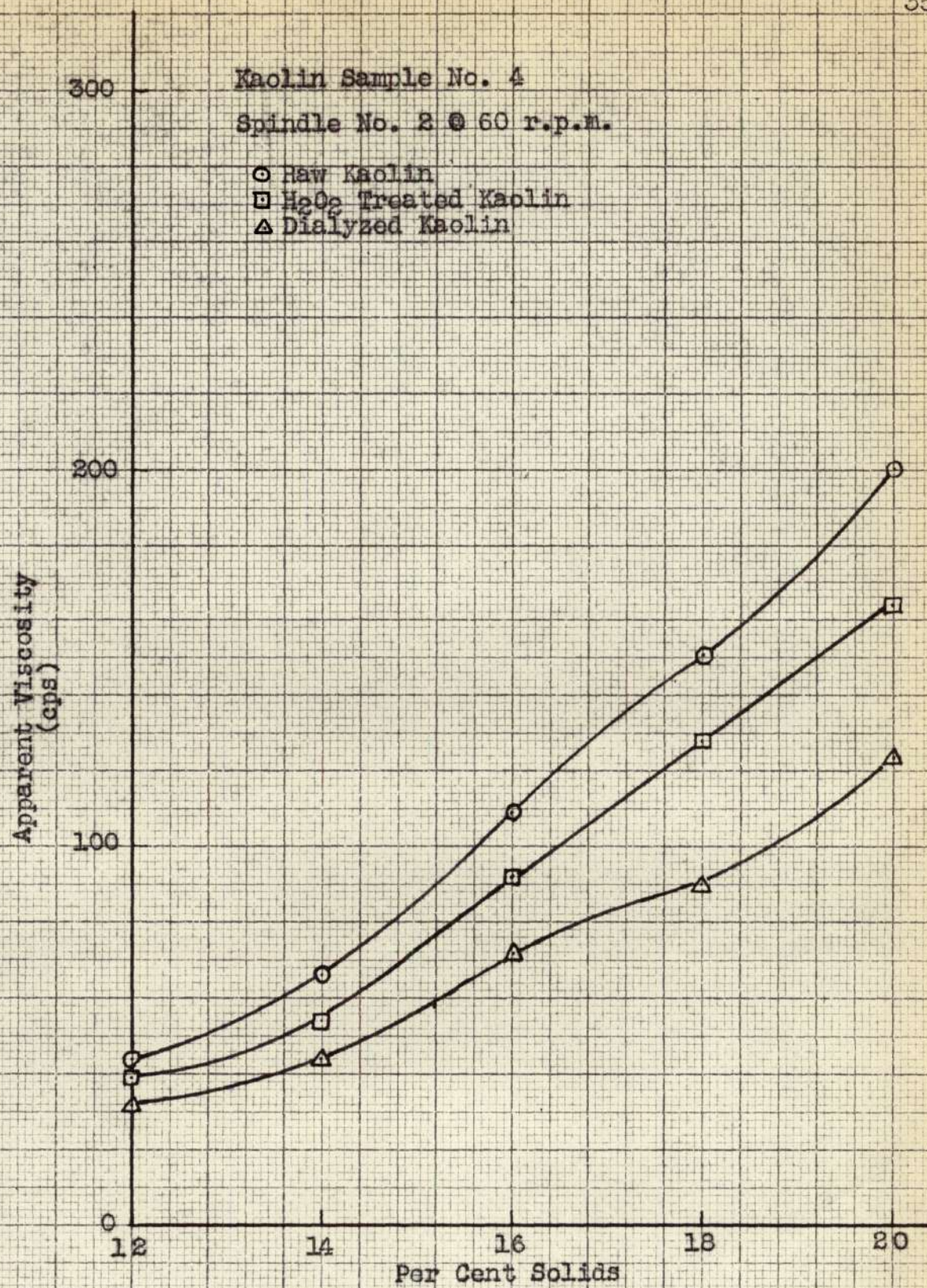


Fig. 5  
Apparent Viscosity Versus Per Cent Solids



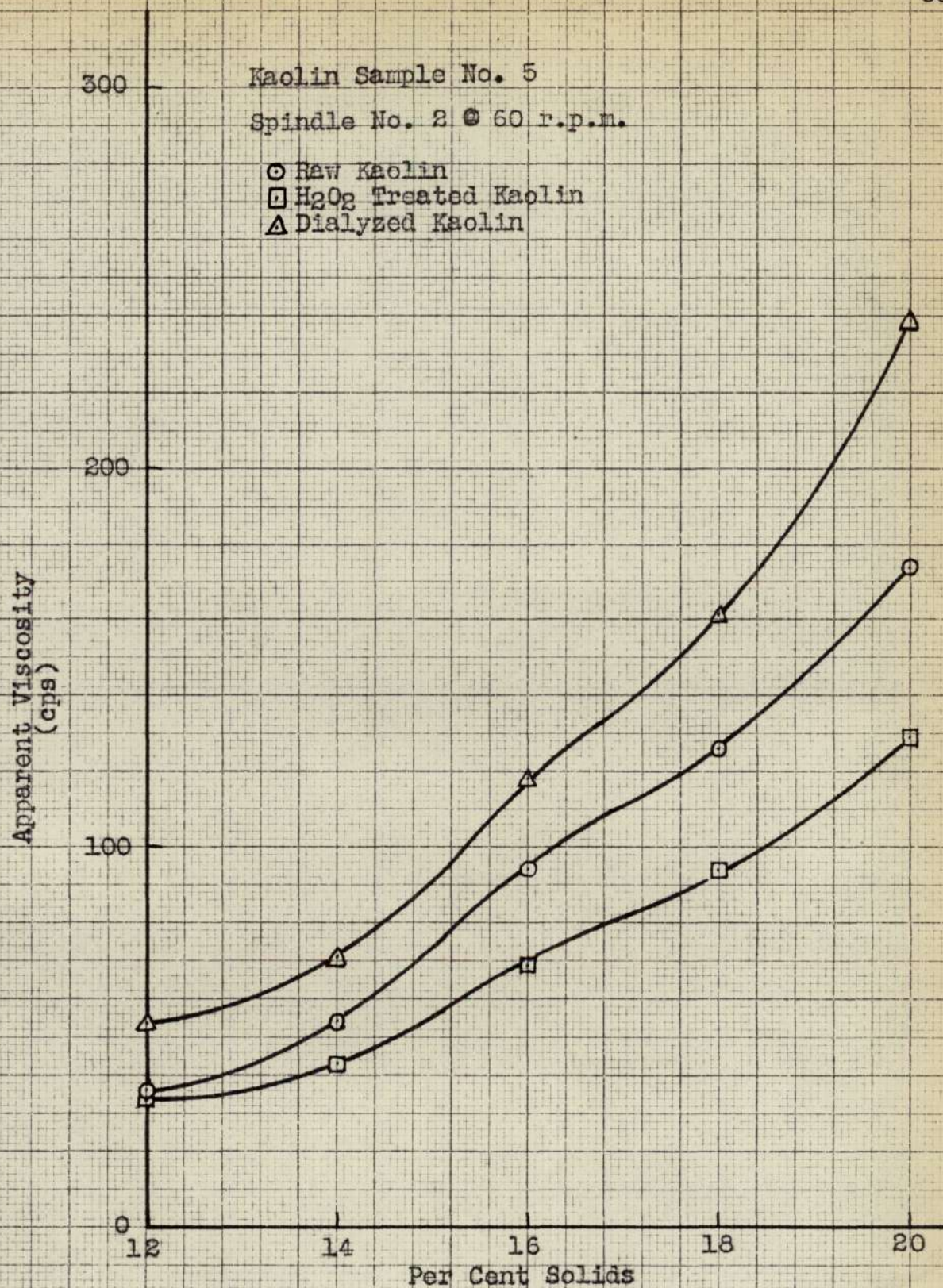


Fig. 6  
Apparent Viscosity Versus Per Cent Solids



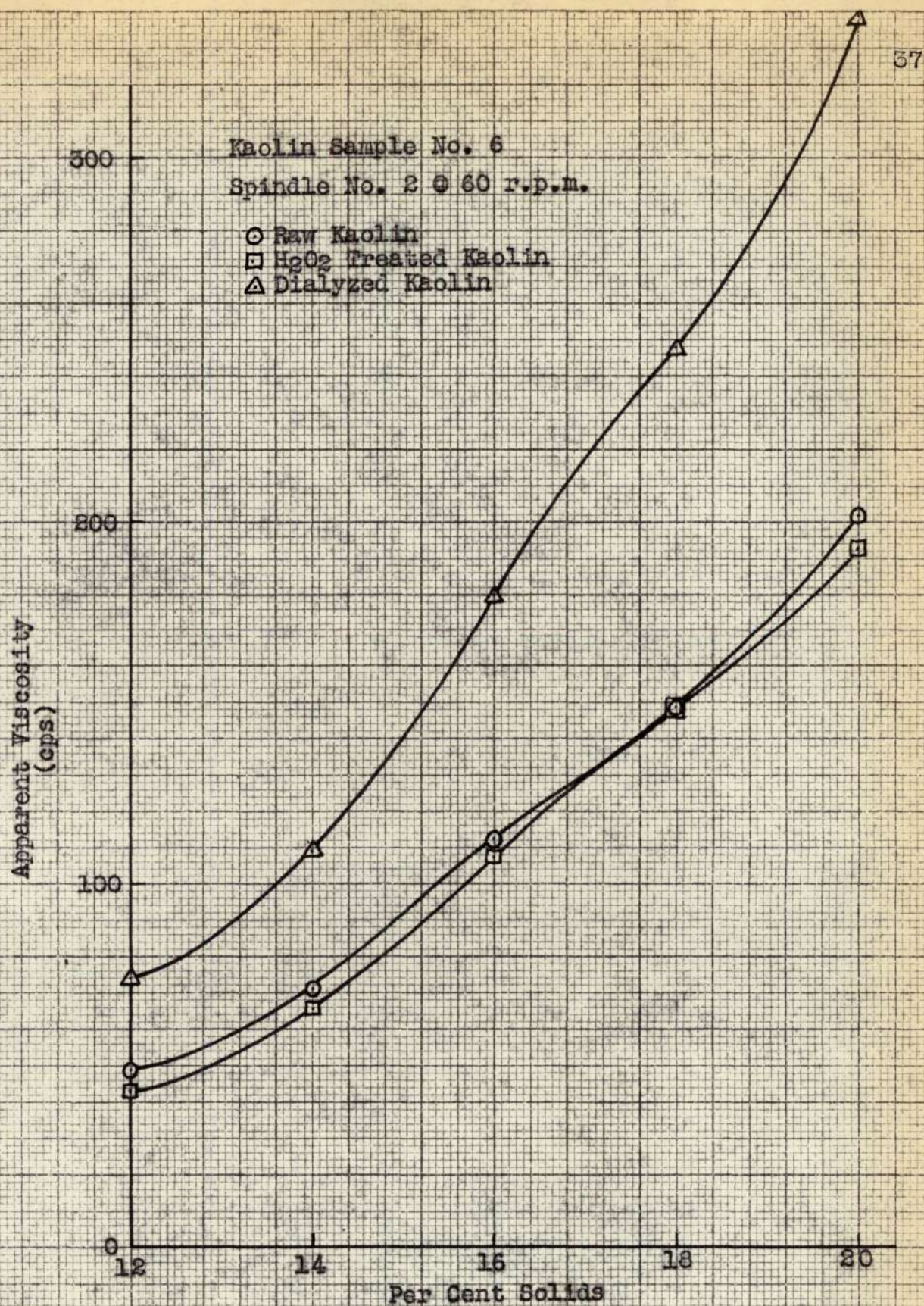


Fig. 7  
Apparent Viscosity Versus Per Cent Solids



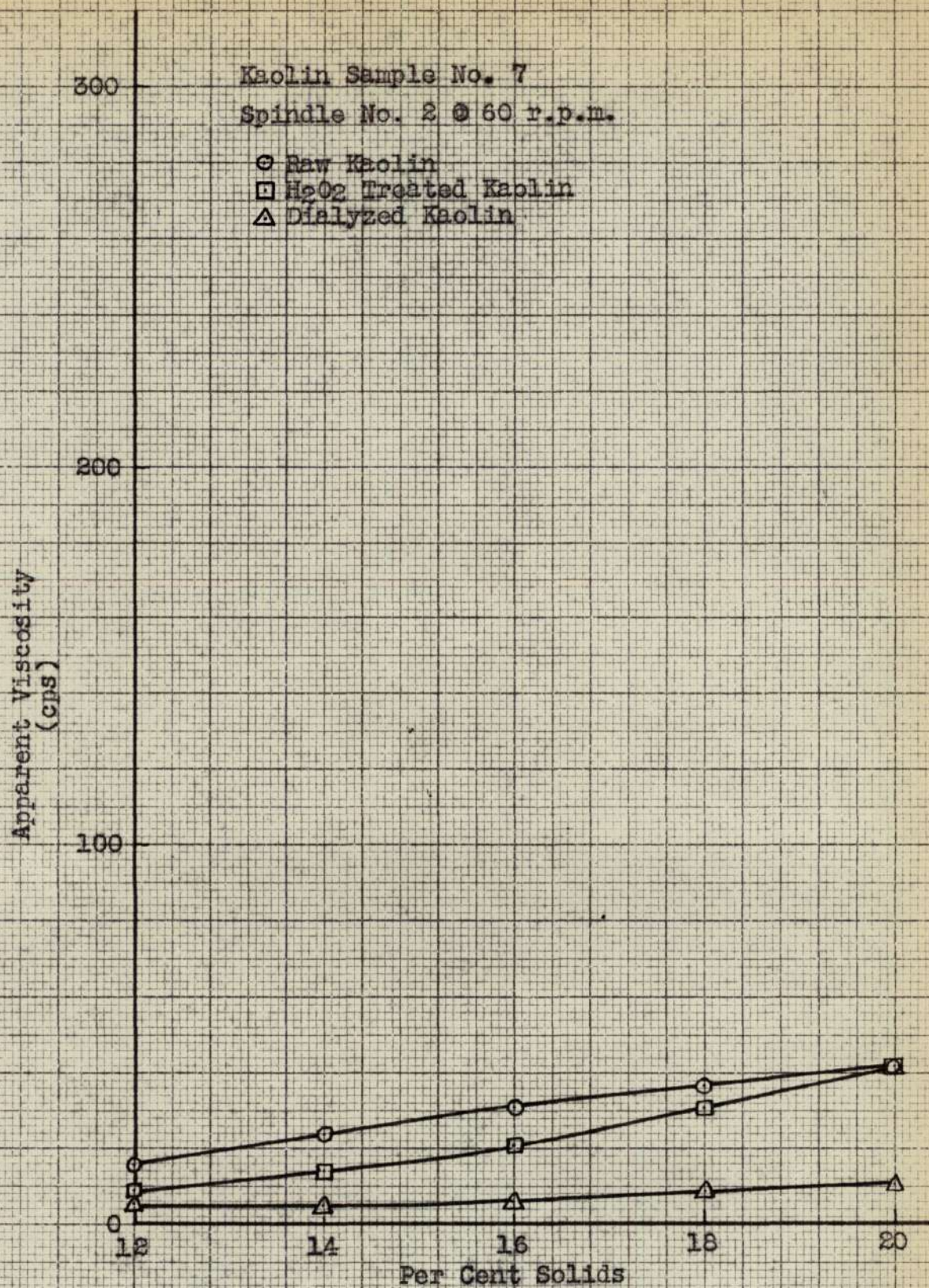


Fig. 8  
Apparent Viscosity Versus Per Cent Solids







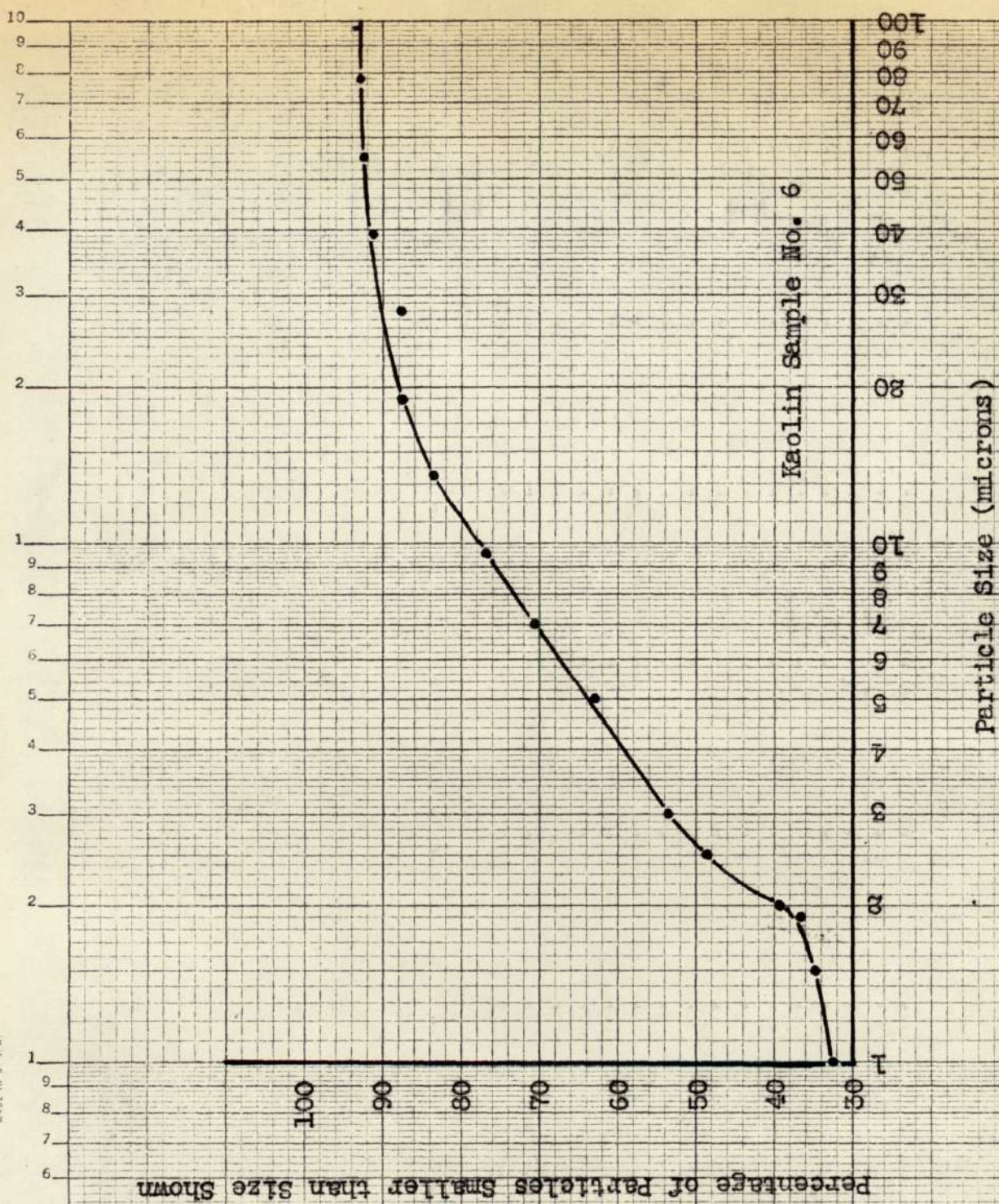


Fig. 9  
Grain Size Accumulation Curve



Table 9

## Chemical Analysis

Kaolin No.	1	2	3	4	5	6	7
SiO <sub>2</sub>	45.46	44.22	45.75	42.54	43.83	41.53	41.10
TiO <sub>2</sub>	1.66	1.76	1.19	1.40	1.46	1.42	1.67
Al <sub>2</sub> O <sub>3</sub>	34.81	39.01	38.06	38.63	40.53	40.49	38.24
Fe <sub>2</sub> O <sub>3</sub>	1.67	1.74	1.06	1.36	0.84	0.83	0.41
P <sub>2</sub> O <sub>5</sub>	0.00	Trace	0.00	0.00	Trace	0.00	0.00
CaO	0.24	0.98	0.31	0.24	0.50	0.45	0.47
MgO	0.57	0.55	0.50	1.65	1.33	1.08	1.48
Free H <sub>2</sub> O	0.96	1.02	0.64	0.34	0.48	0.65	3.14
Ignition Loss	12.20	13.69	13.61	13.78	13.89	13.52	12.55
Totals	97.57%	102.97%	101.12%	99.94%	102.86%	99.97%	99.07%

Analyses Performed By: Mrs. Hilderbrand, Ga. Tech Engineering Experiment Station.



Differential Temperature  
(mV)

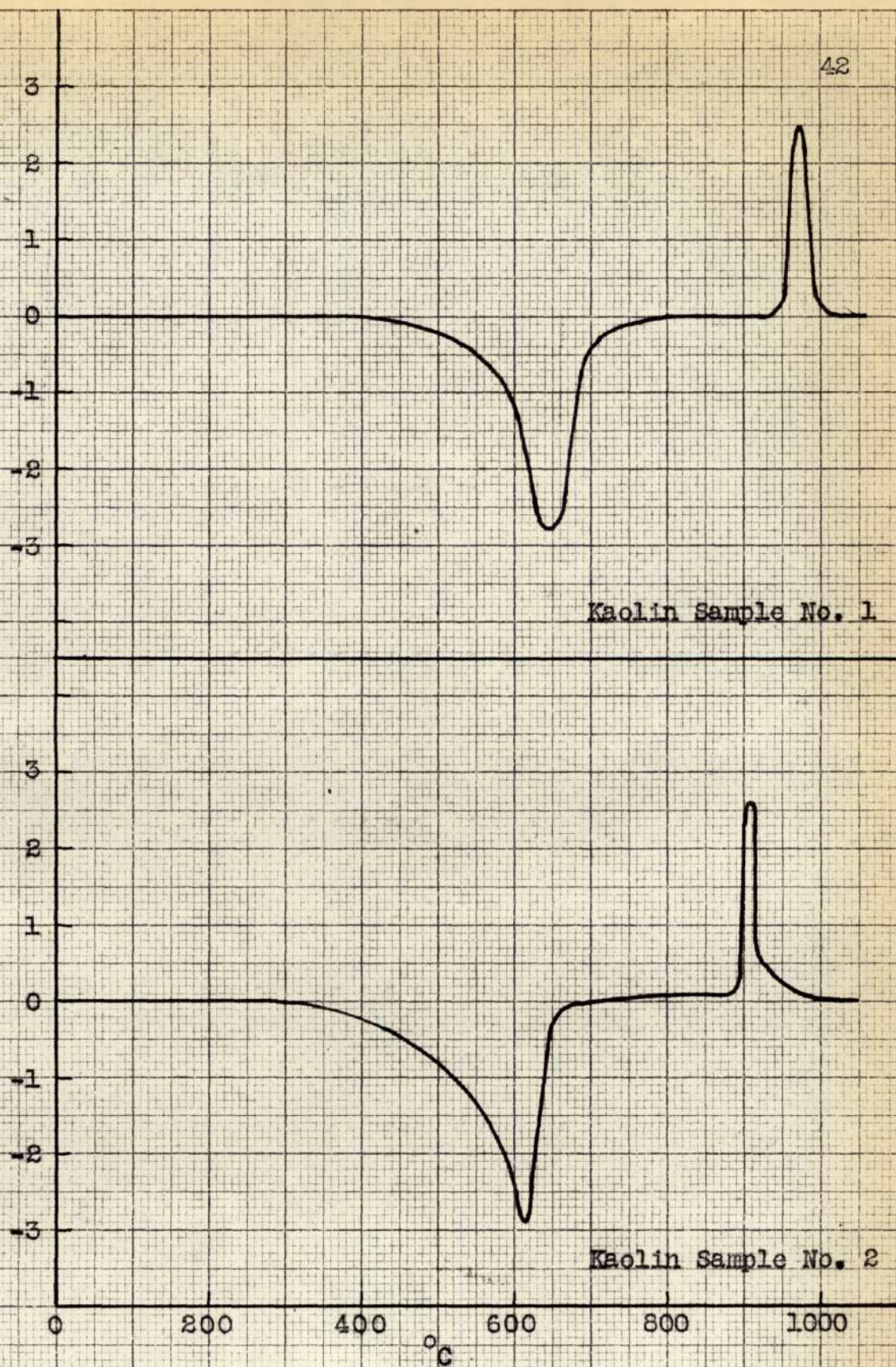


Fig. 10  
Differential Thermal Analysis



Differential Temperature  
(mvs)

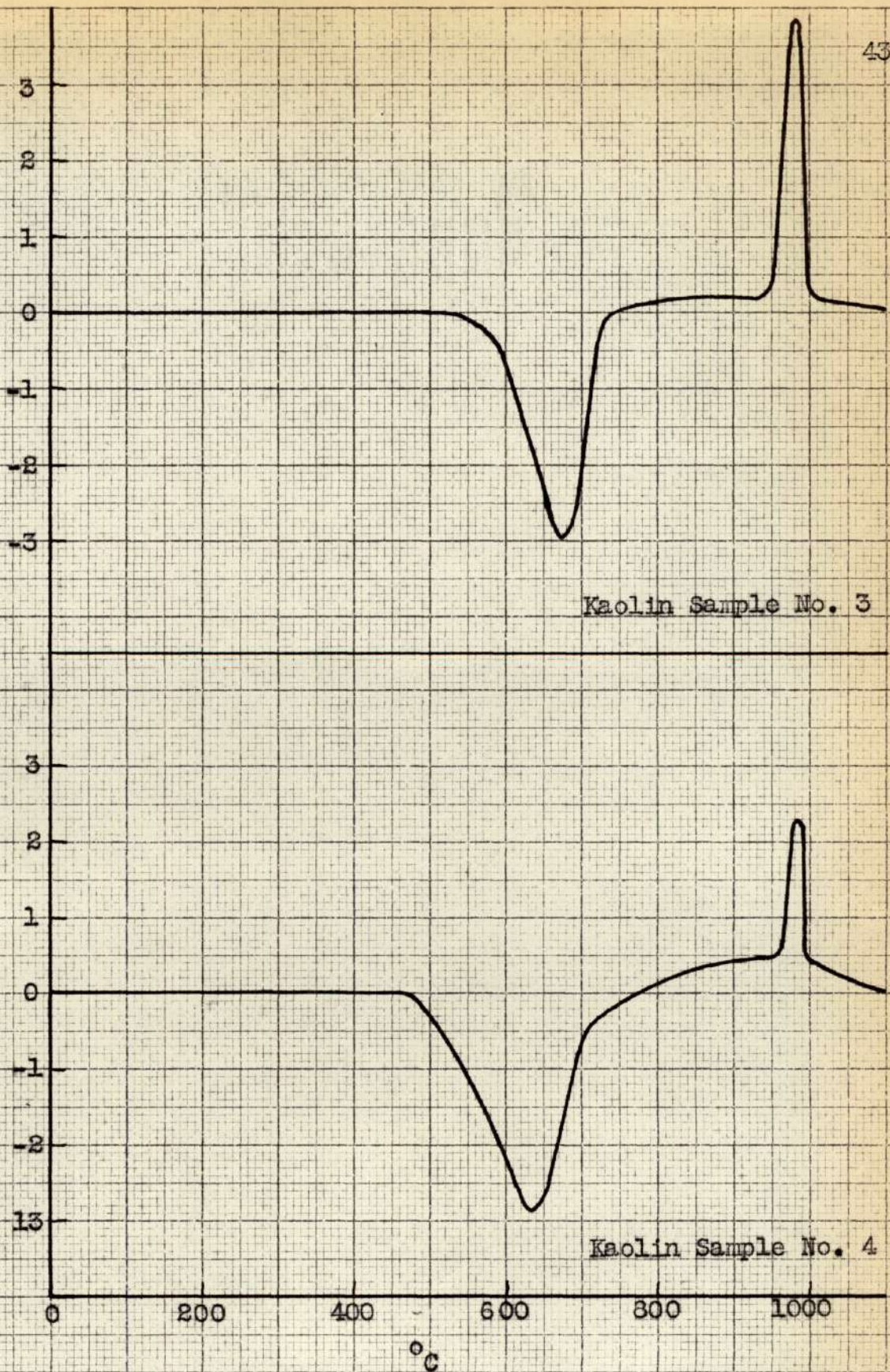


Fig. 11  
Differential Thermal Analysis



Differential Temperature  
(mV)

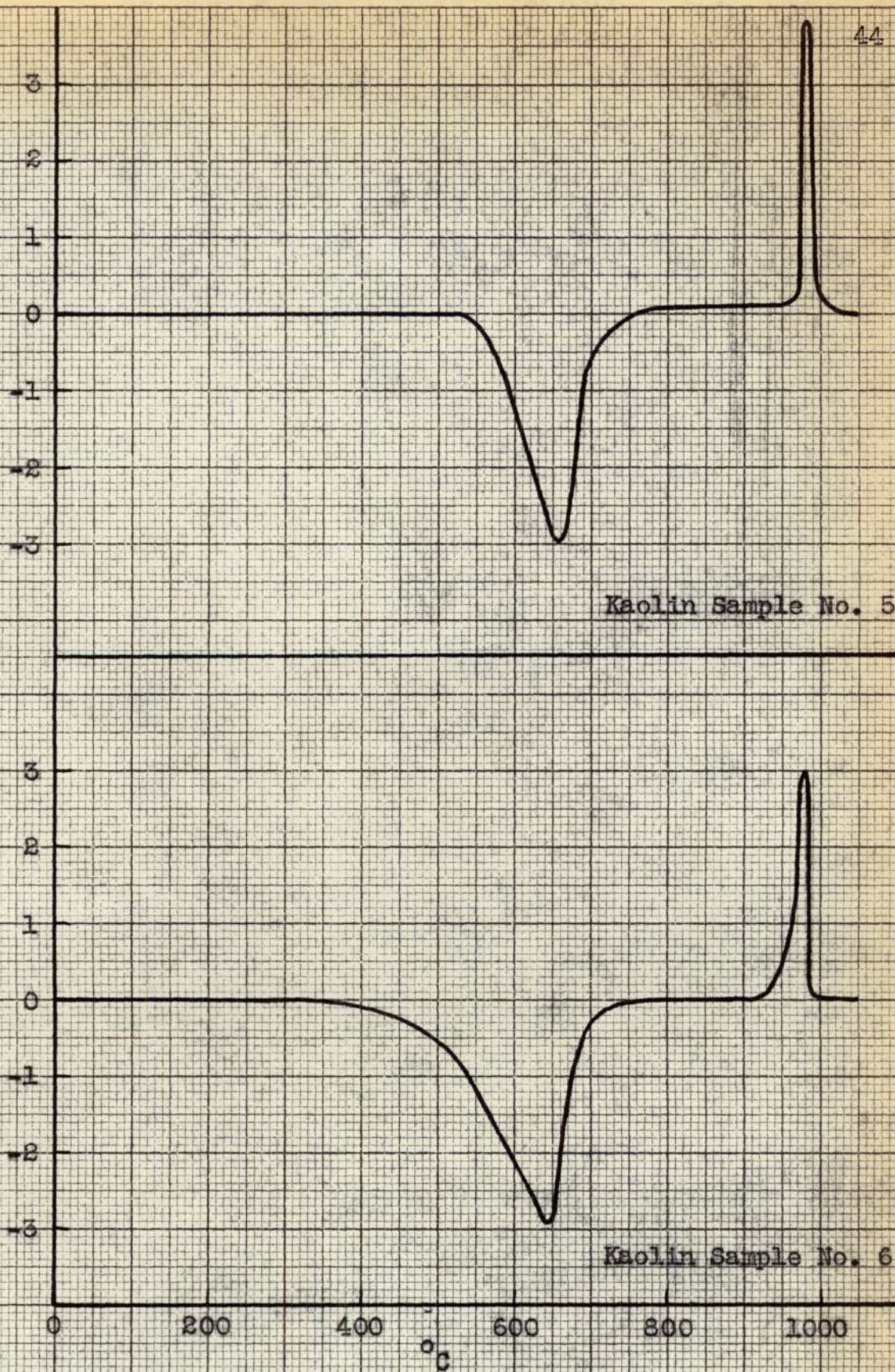


Fig. 12  
Differential Thermal Analysis



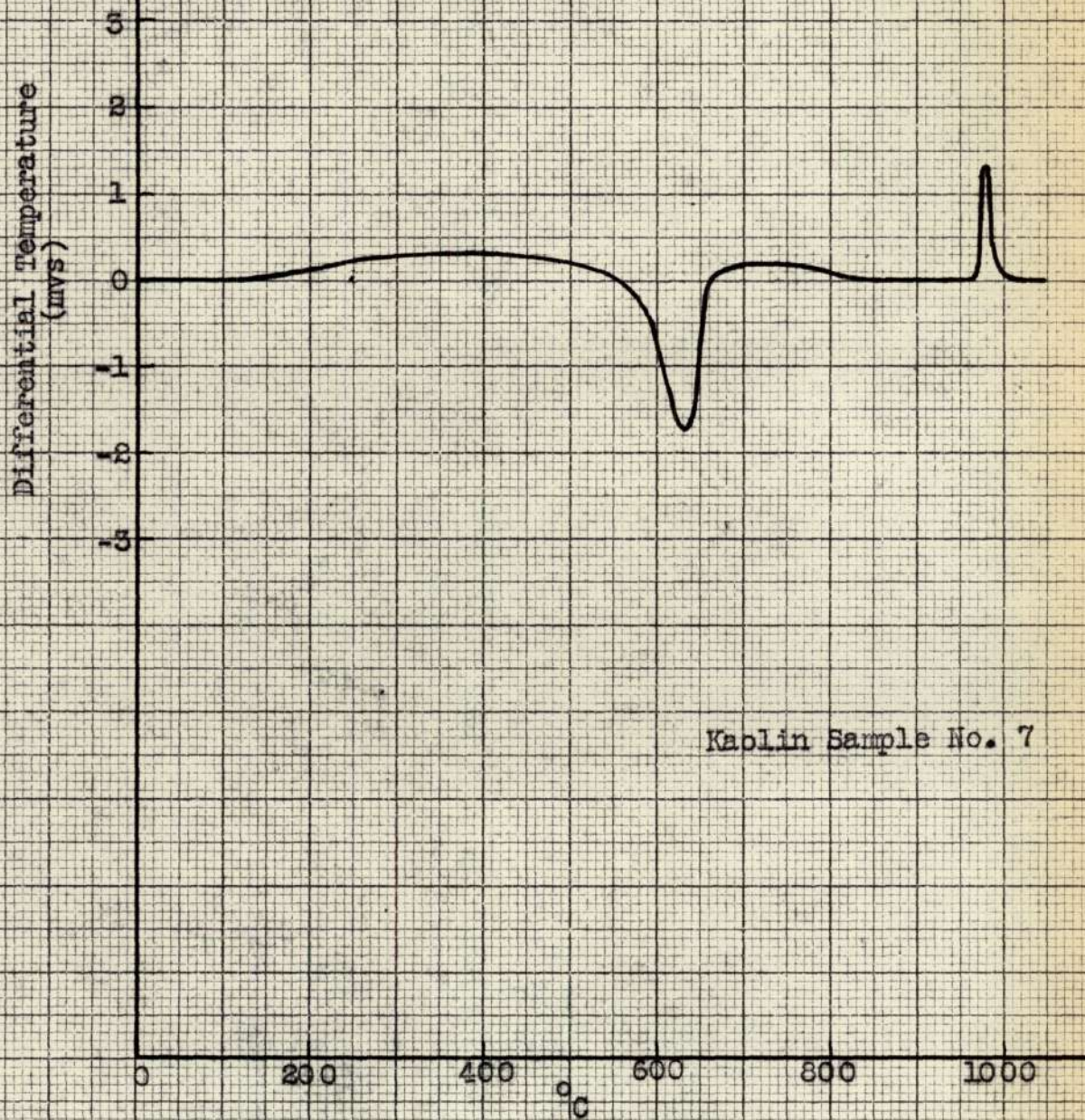


Fig. 13  
Differential Thermal Analysis



Table 10

## X-ray Analysis

Kaolin No.	$\frac{(020)}{(010)} \times 100^*$			$\frac{(020)}{(111)} \times 100^*$			Approximate C Dimension A° From (002)		
	Crude	H <sub>2</sub> O <sub>2</sub> Treated	Dialyzed	Crude	H <sub>2</sub> O <sub>2</sub> Treated	Dialyzed	Crude	H <sub>2</sub> O <sub>2</sub> Treated	Dialyzed
1	-	119	122	180	138	141	-	475	475
2	-	131	125	-	161	163	-	475	475
3	74	85	83	82	97	101	800	690	785
4	74	86	88	93	101	104	800	920	785
5	90	100	100	100	124	121	420	388	440
6	96	109	104	136	127	137	450	560	475
7	138	110	121	104	130	117	1100	920	1100

\* Ratio of Peak Heights or Intensity Ratio.

Analysis Performed By: Mr. Ray Young, Ga. Tech Engineering Experiment Station



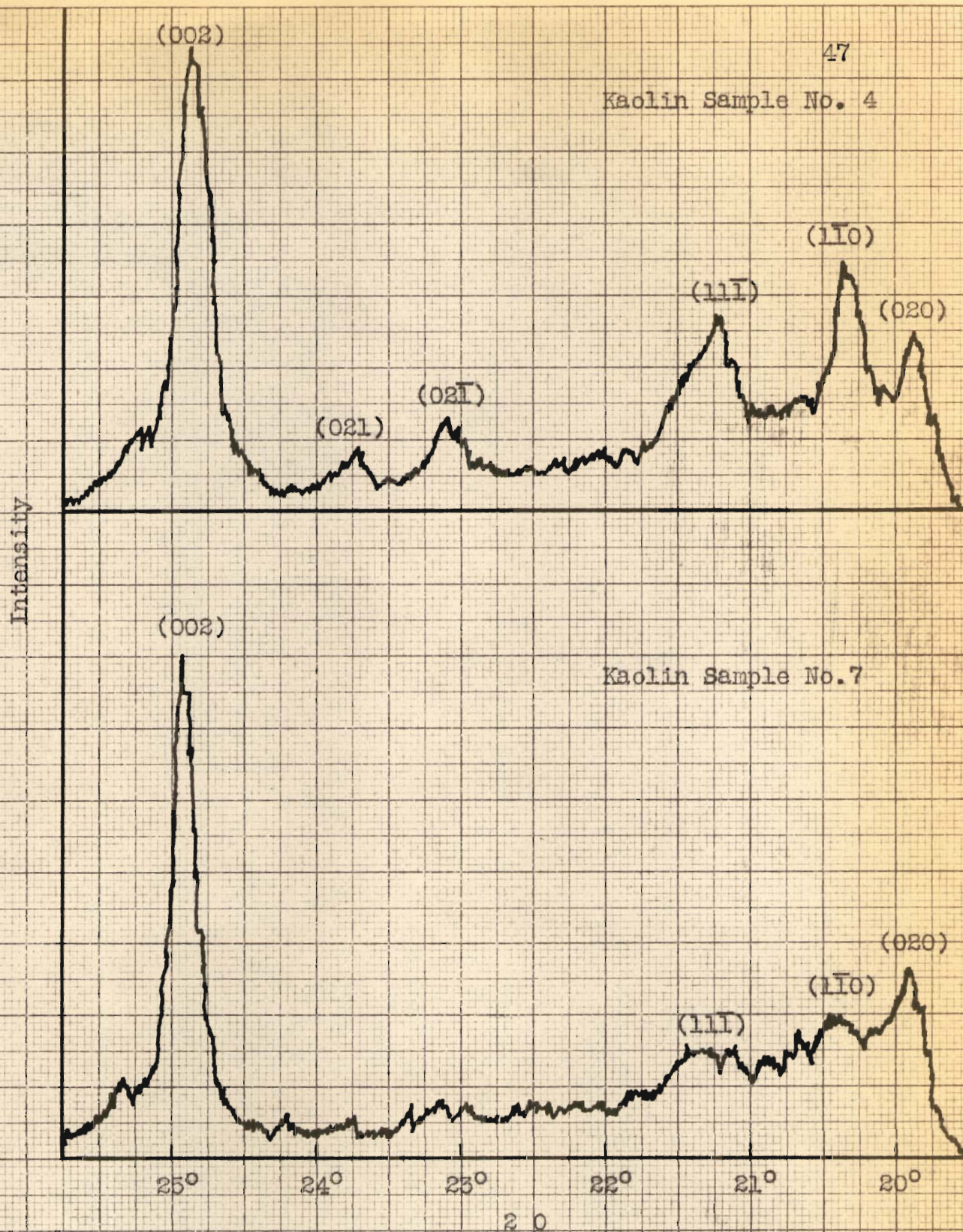


Fig. 14  
X-ray Diffraction Trace



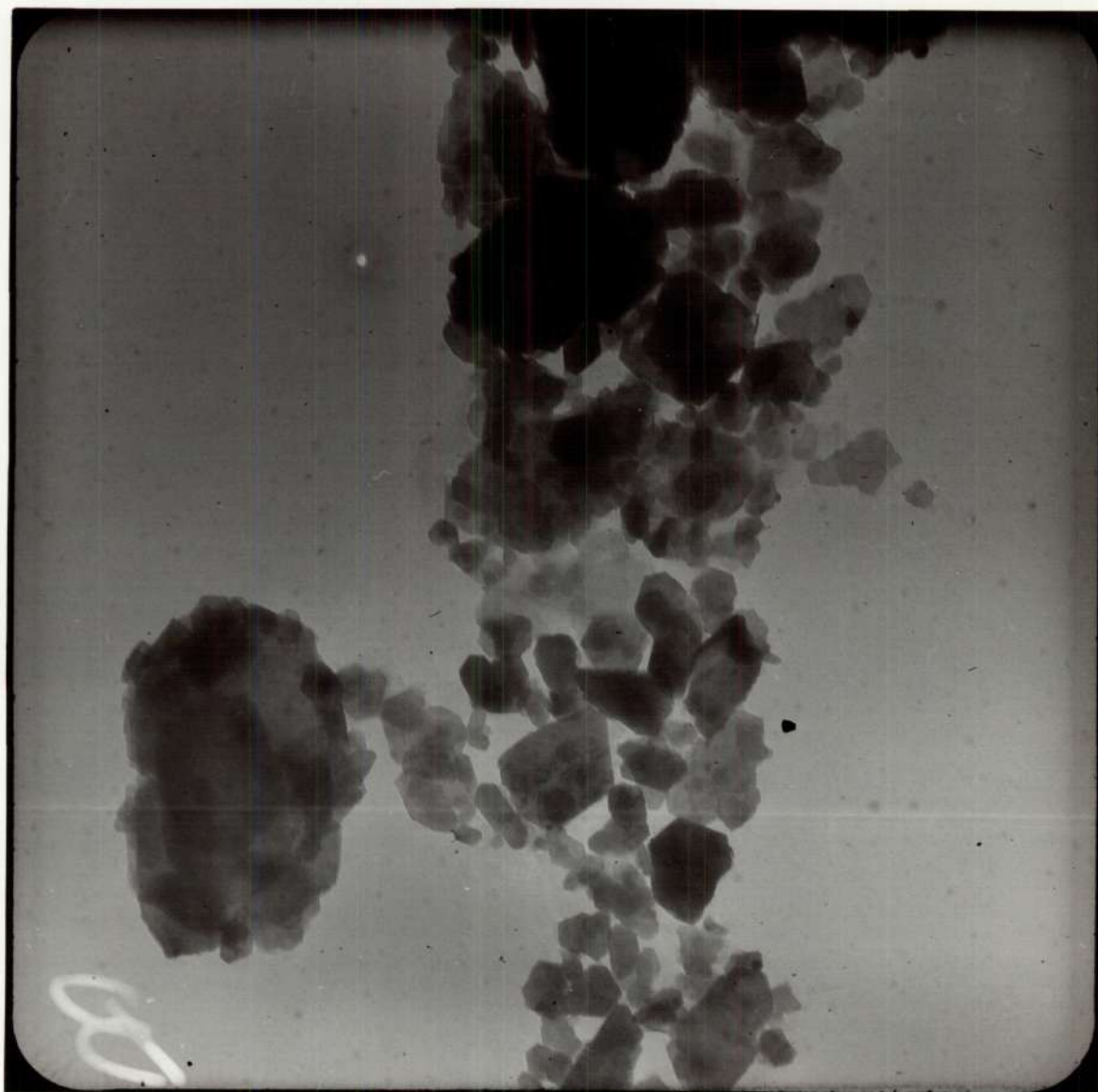


Fig. 15  
Kaolin Sample No. 1  
(24900 X)



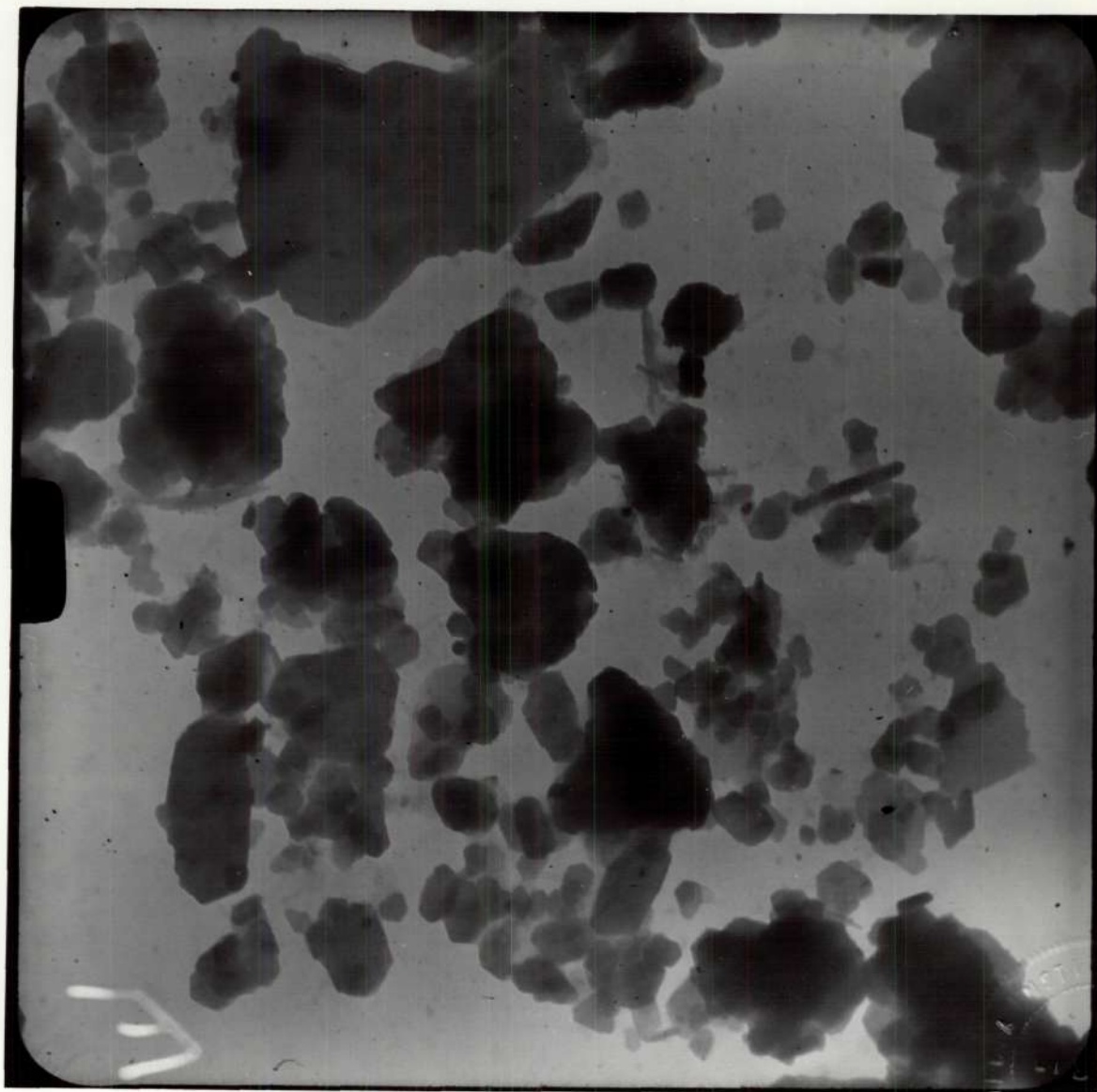


Fig. 16  
Kaolin Sample No. 2  
(24900 X)

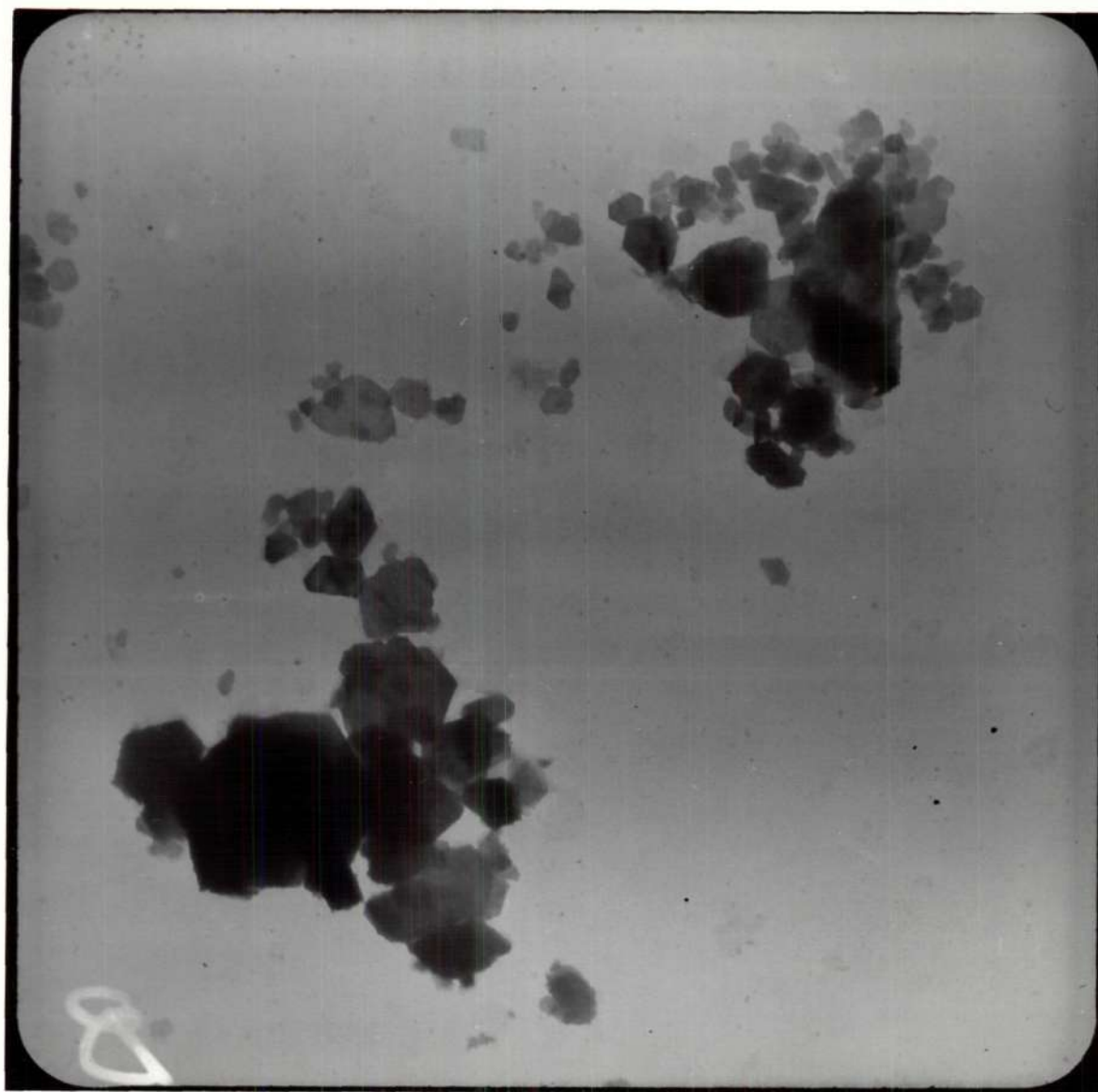


Fig. 17  
Kaolin Sample No. 3  
(17400 X)



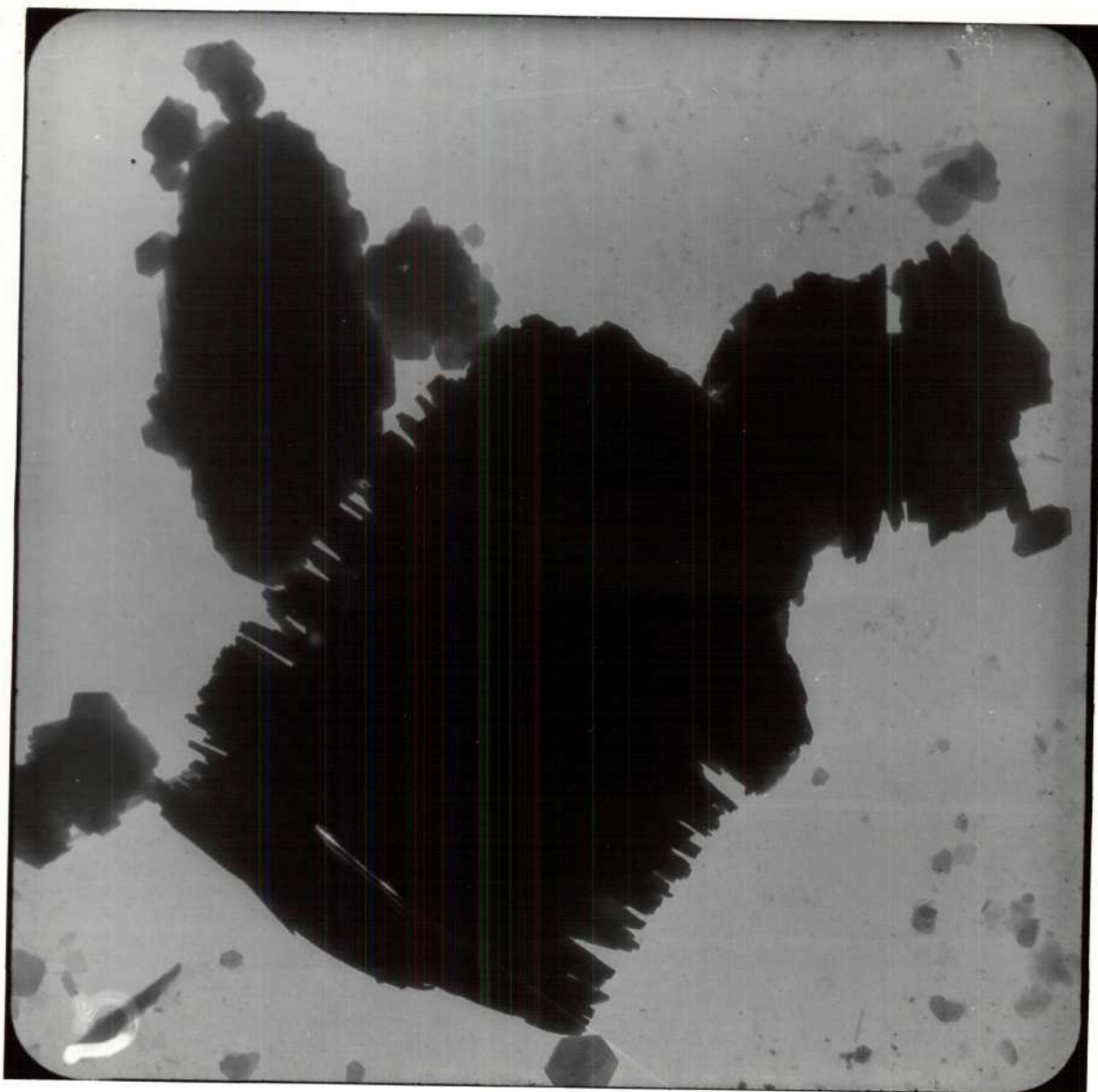


Fig. 18  
Kaolin Sample No. 4  
(17400 X)

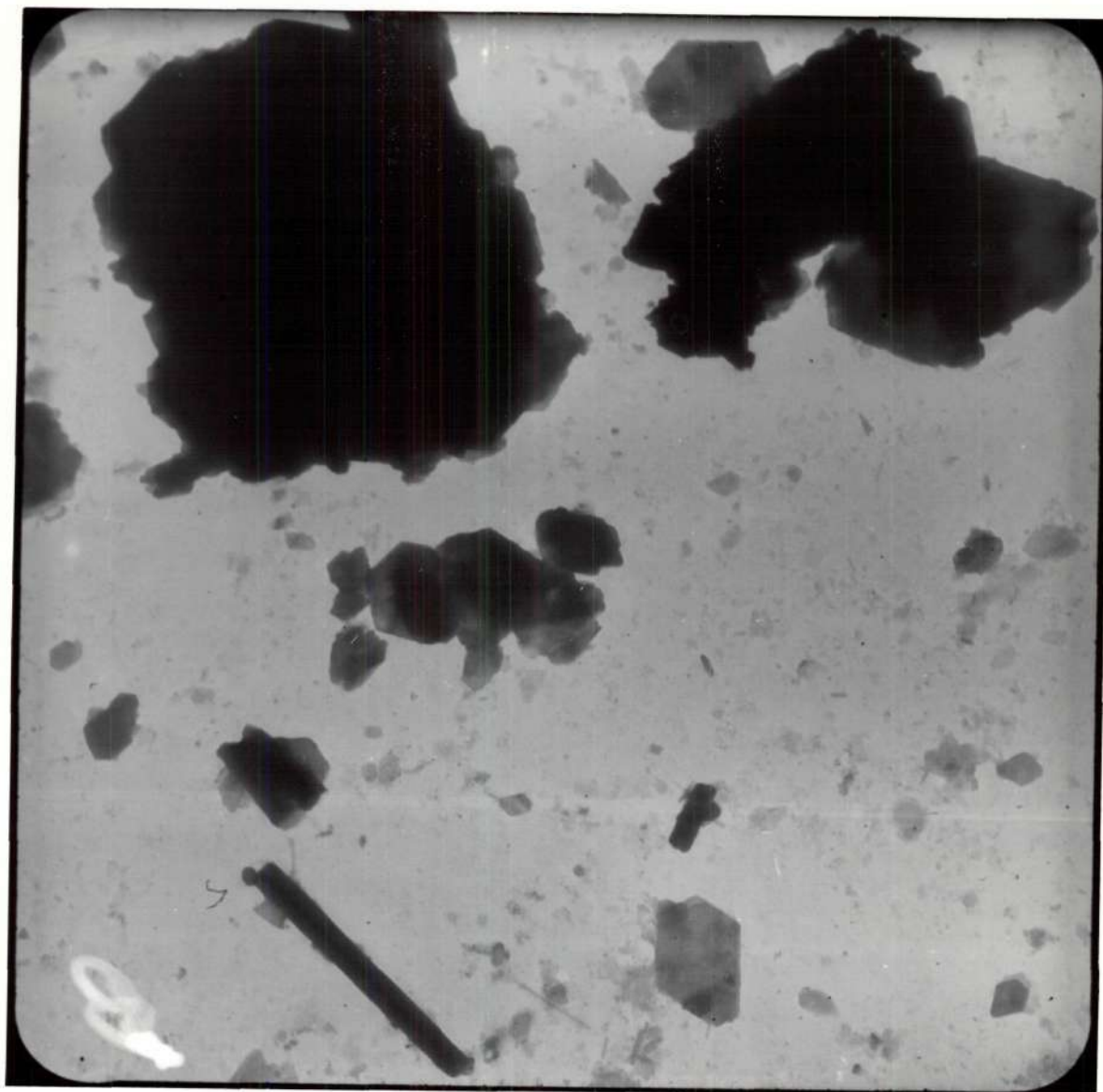


Fig. 19  
Kaolin Sample No. 4  
(17400 X)



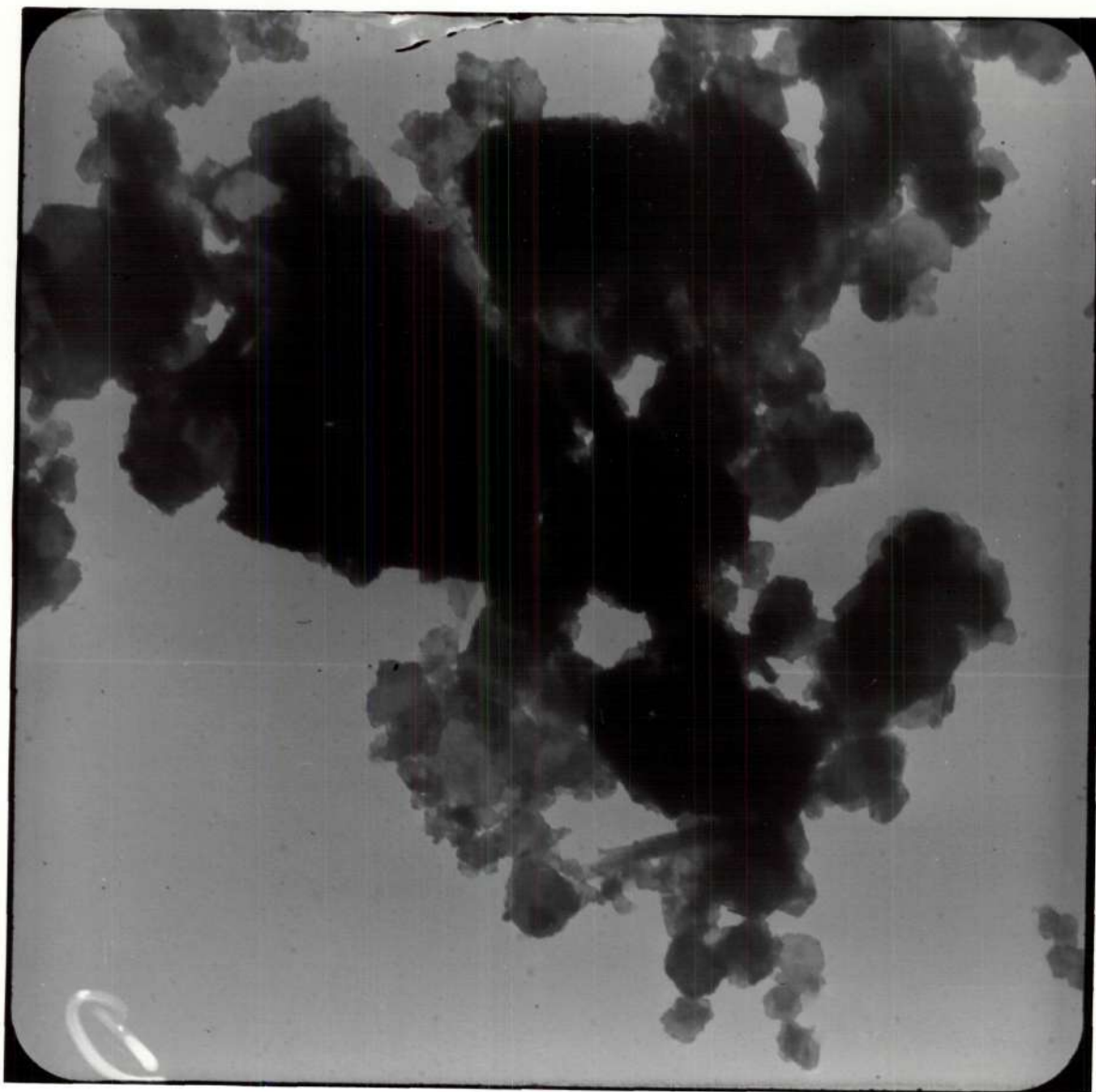


Fig. 20  
Kaolin Sample No. 5  
(17400 X)



Fig. 21  
Kaolin Sample No. 6  
(6900 X)



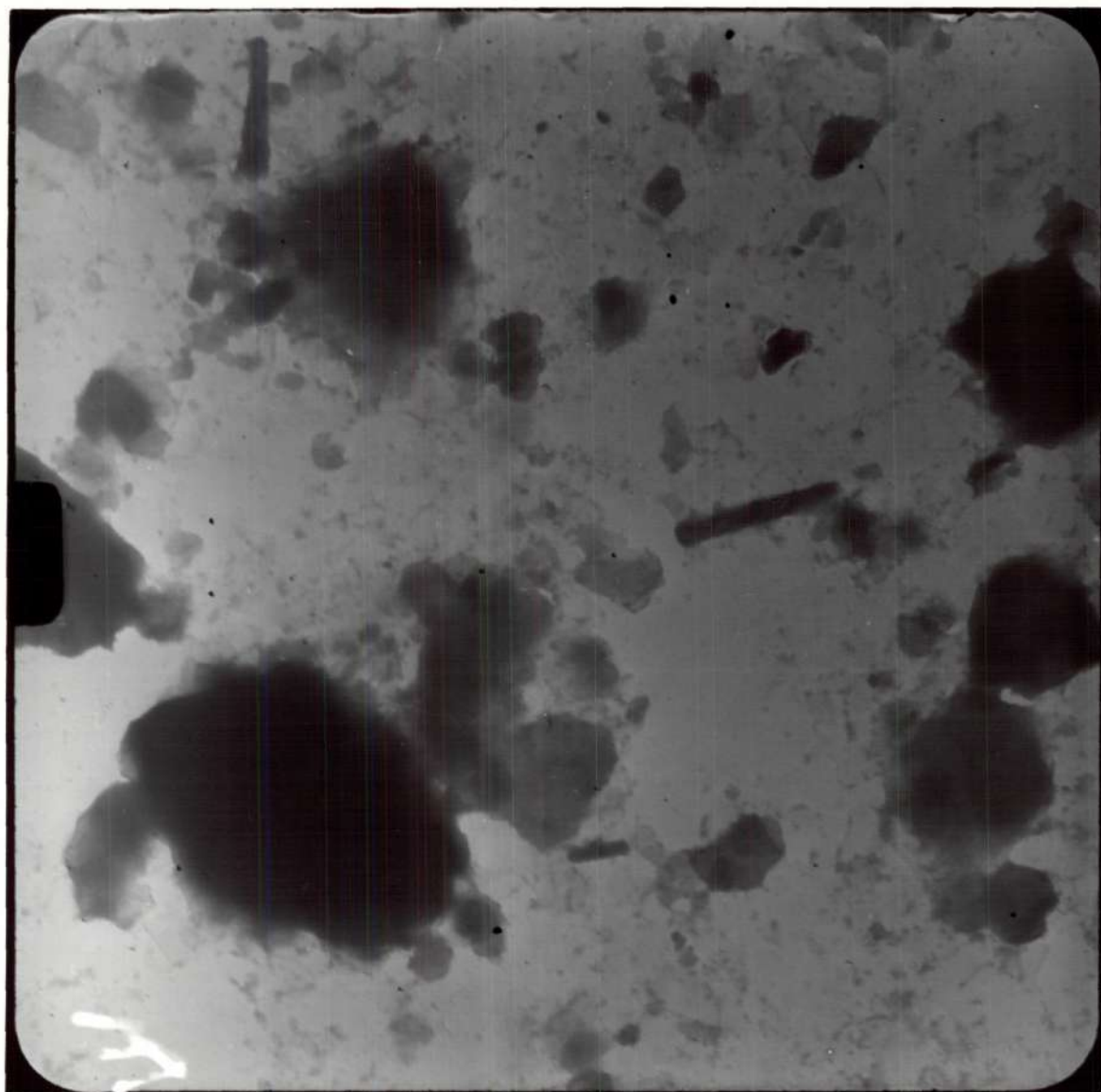


Fig. 22  
Kaolin Sample No. 7  
(17400 X)

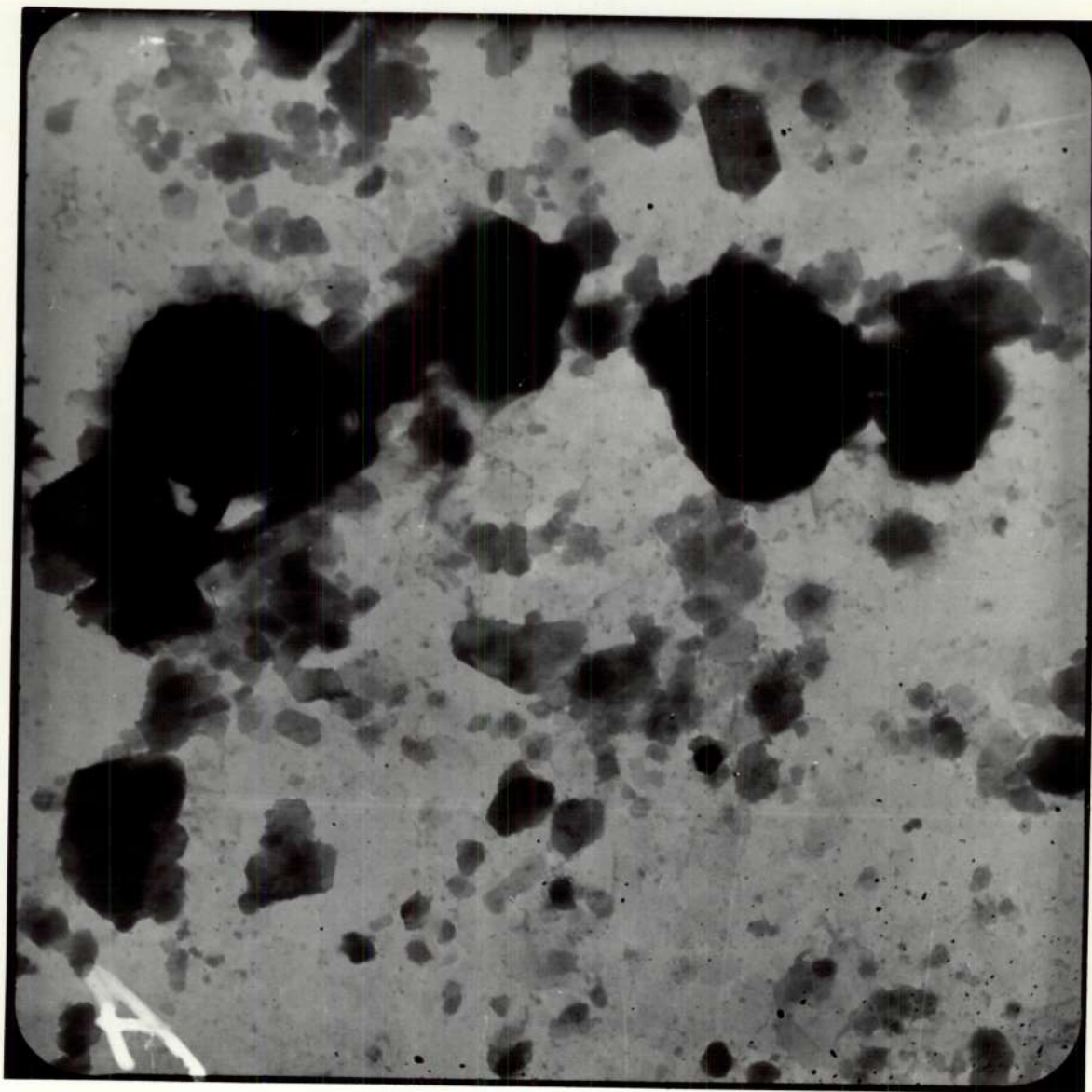


Fig. 23  
Kaolin Sample No. 7  
(17400 X)



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